User Manual and Examples for

UI-SIMCOR v2.6

Multi-Site Substructure Pseudo-Dynamic Simulation Coordinator

NEES-SAM v2.0

Static Analysis Module for NEESgrid

by

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UI-SIMCOR Update History

June 2004

- Version 1.0 release

June 2005

- Version 1.3 release
- Renamed SIMCOR to UI-SIMCOR
- Renamed FedeasMDL to NEES-FL for consistency
- Inclusion of NEES-MW
- Development of GUI for UI-SIMCOR
- Include the latest version of OpenSees (version 1.6.2) and FEDEAS Lab (version 2.6)
- Include example input files for OpenSees and ZEUS-NL for MOST example
- Development of an adapter module, NEES-MW, by Sung Jig Kim for experimental equipments (LBCB) in UIUC

October 2006

- Version 2.0 release
- Reconstruct the architecture of UI-SIMCOR using object-oriented approach
- Modulize the main body of analysis algorithm (α-OS scheme)
- Provide improved GUI to monitor the remote site
- Development of NEES-ABAQUS for ABAQUS static analysis module by Gun Jin Yun
- Include example input files for ABAQUS for buckling example
- Remove NEES-MW
- Update UI-SIMCOR for experimental equipment (LBCB) in UIUC by Kyu-Sik Park
- Include LBCB example
- Include API for μNEES facility in UCB
- Include one-site experiment using μNEES facility in UCB
- Include two-site experiment between UIUC and UCB using μNEES and MiniMOST 1 facilities
- Include two-site experiment between UIUC and SDSC using MiniMOST 1 facilities
- Include three-site experiment among UIUC, UCB, and SDSC using μNEES and MiniMOST 1 facilities

November 2006

- Version 2.5 release
- Logo change

February 2007

- Version 2.6 release
- Include OpenFresco1D and NHCP communication protocols
- Include SDOF example using OpenFresco1D and NHCP communication protocols
- Include 7-DOF example using TCP/IP, LabVIEW1, LabVIEW2, OpenFresco1D, and NHCP communication protocols
- Include two-site experiment between UIUC and SDSC using MiniMOST 1 facilities through NHCP

NEES-SAM Update History

June 2004

- Version 1.0 release

June 2005

- Version 1.5 release
- Interact with the latest version of OpenSees (version 1.6.2), which include soil material model and can make reaction force output. Hence it isn't necessary anymore to add additional nodes with stiff springs on the control points to measure reaction forces.
- Minor interface updates.

October 2006

- Version 2.0 release
- Develop three NEES-SAM for TCP/IP, LabVIEW1, and LabVIEW2 protocols
- Minor interface updates.

1. Introduction

MOST, Multi-Site Online Simulation Test, experimental example has been extensively used to verify the NEESgrid infrastructure. The simulation coordinator for the MOST experiment (http://it.nees.org/software/ntcp/index.php) is designed only for the MOST experiment. Eventually, more than three sites are going to be involved in the earthquake simulation and various structural configurations need to be tested. The UI-SIMCOR is developed for this purpose. UI-SIMCOR can control distributed pseudo-dynamic (PSD) test in several sites. The number of sites and number of control points are not limited. Using this software in together with various communication protocols, we can test from a single degree of freedom system to highly complicated structures which need to be tested in various sites. The simulation can be either all experiments, combination of experiments and analyses, or all analyses.

In this documentation, the simulation framework, brief theoretical background, test procedure, protocol specification, installation guide, etc. are introduced from Section 2 to Section 7. In Section 8, various numerical examples are introduced. Single degree of freedom (SDOF) system is used to show how to prepare configuration files and how to run the analysis. Inelastic SDOF system with initial loading is introduced to explain a method to impose an initial static force. In the later version of UI-SimCor, the time-independent static forces will be applied in UI-SimCor not in static modules. SDOF system with concrete material is also given to demonstrate the capability of the ZEUS-NL and OpenSees. MOST example and three-story three-bay steel structure, which is a part of three-story SAC building, are given. Furthermore, example for Loading and Boundary Condition Box (LBCB) in UIUC is explained. This example can be used as a basis when experimental equipment has different number of actuators from the number of effective DOFs in UI-SIMCOR. Finally, various experiments using UI-SIMCOR at University of Illinois at Urbana-Champaign (UIUC), University of California at Berkeley (UCB), and San Diego Supercomputer Center (SDSC) are given in Section 9 to demonstrate the efficacy of UI-SIMCOR. Furthermore, the detailed procedure for two- and three-site experiments is explained in Appendix. This experiment procedure can be used as a basis of other experiment with different facilities using UI-SIMCOR.

2. Simulation Framework

In the developed framework, the integration scheme (α-OS scheme, Combescure and Pegon, 1997) is modulized which enables users to easily implement new integration algorithm and all other modules perform static analysis or experiment. For instance, the MOST experiment example in NEESgrid 3.2 (Nakata et. al., 2003) consists of simulation coordinator, left column tested in UIUC, right column tested in University of Colorado (UCOL), and remaining elements in National Center for Supercomputing Applications (NCSA). NCSA site had pseudo-dynamic integration scheme in it. In UI-SIMCOR, all sites, UIUC, UCOL, and NCSA, run static analysis or static experiments. Integration scheme resides in simulation coordinator.

UI-SIMCOR can communicate through TCP/IP, LabVIEW1, LabVIEW2, OpenFresco1D, and NHCP protocols with any experimental equipment or static analysis modules. These protocols will be explained in detail in Chapter 6. Static analysis application, which can take displacement inputs and make reaction force outputs can participate in the simulation as a static analysis module. For this purpose, an interface for FEDEAS Lab, ZEUS-NL, OpenSees, ABAQUS, OpenFresco, and NHCP Simulation Server are developed. FEDEAS Lab and ABAQUS communicate with LabVIEW2 protocol. ZEUS-NL, OpenSees, and experimental modules communicate with TCP/IP, LabVIEW1, and LabVIEW2 protocols in which ASCII code is used to send and receive information. OpenFresco communicate with OpenFresco1D protocol. NHCP Simulation Server, MiniMOST 1 and 2 at UIUC or SDSC communicate with NHCP. However, OpenFresco1D and NHCP are not generalized yet. The generalized version of OpenFresco1D and NHCP will be available in the next version of UI-SIMCOR. If the experiment site uses different protocol to communicate with actuator, then the experiment site should provide a method of communication. Any program language which can impose displacement and collect measured displacement and force from experiment can be used. The Application Program Interface (API) is also need for communication between UI-SIMCOR and experiment site. The API will be further explained through the experiment example in Section 9.1.

Figure 1 shows the framework of the simulation. The complete segregation of integration scheme from static analysis module allows any combination of experiments and analyses.

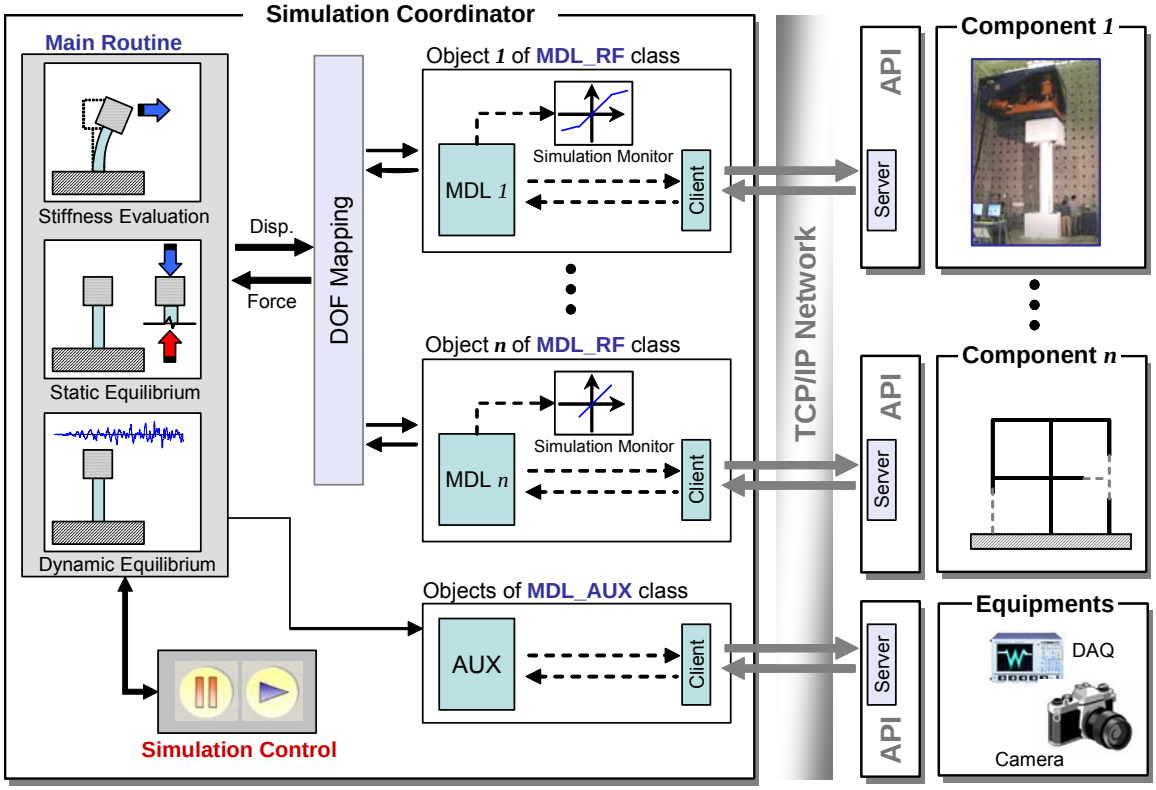


Figure 1 Hybrid simulation framework

3. Pseudo-Dynamic Test Procedure

In UI-SIMCOR, pseudo-dynamic test consists of roughly four stages; initialization, initial stiffness formulation, static loading, and dynamic loading stages. During *initialization stage*, the UI-SIMCOR makes connections to experimental sites or simulation module and initializes each module. Most variables that will be used in later stage are also initialized. During *Initial stiffness formulation stage*, UI-SIMCOR evaluate stiffness matrix of whole structural system. There are two options to establish stiffness matrix. When the structural dimension is large, stiffness matrix can be loaded from files each of which defines stiffness matrix of each module. If the stiffness evaluation is affordable through network, UI-SIMCOR sends predefined displacement for each degree of freedom to each module and take measured forces to establish initial stiffness of the tested structure. The established initial stiffness is used in the *static loading stage* and in the *dynamic loading stage* to determine target displacements. Most structures are resisting gravity forces before they are hit by earthquake. The effect of gravity forces cannot be ignored since the inelastic behavior of columns and beams with initial loading are significantly different from that of the elements without initial loading. During the *static loading stage*, displacements due to this gravity forces are imposed. When there are no gravity forces, this step can be skipped. During *dynamic loading stage*, PSD test using α-OS scheme (Combescure and Pegon, 1997) is performed.

Each experimental stage, i.e., initial stiffness formulation, static and dynamic stages, consists of similar functions such as evaluating target displacements, sending target displacements to each module, executing the commands, checking relaxation, and receiving the measured responses. Figure 2 describes data sequence of data flow of a pseudo-dynamic simulation in UI-SIMCOR.

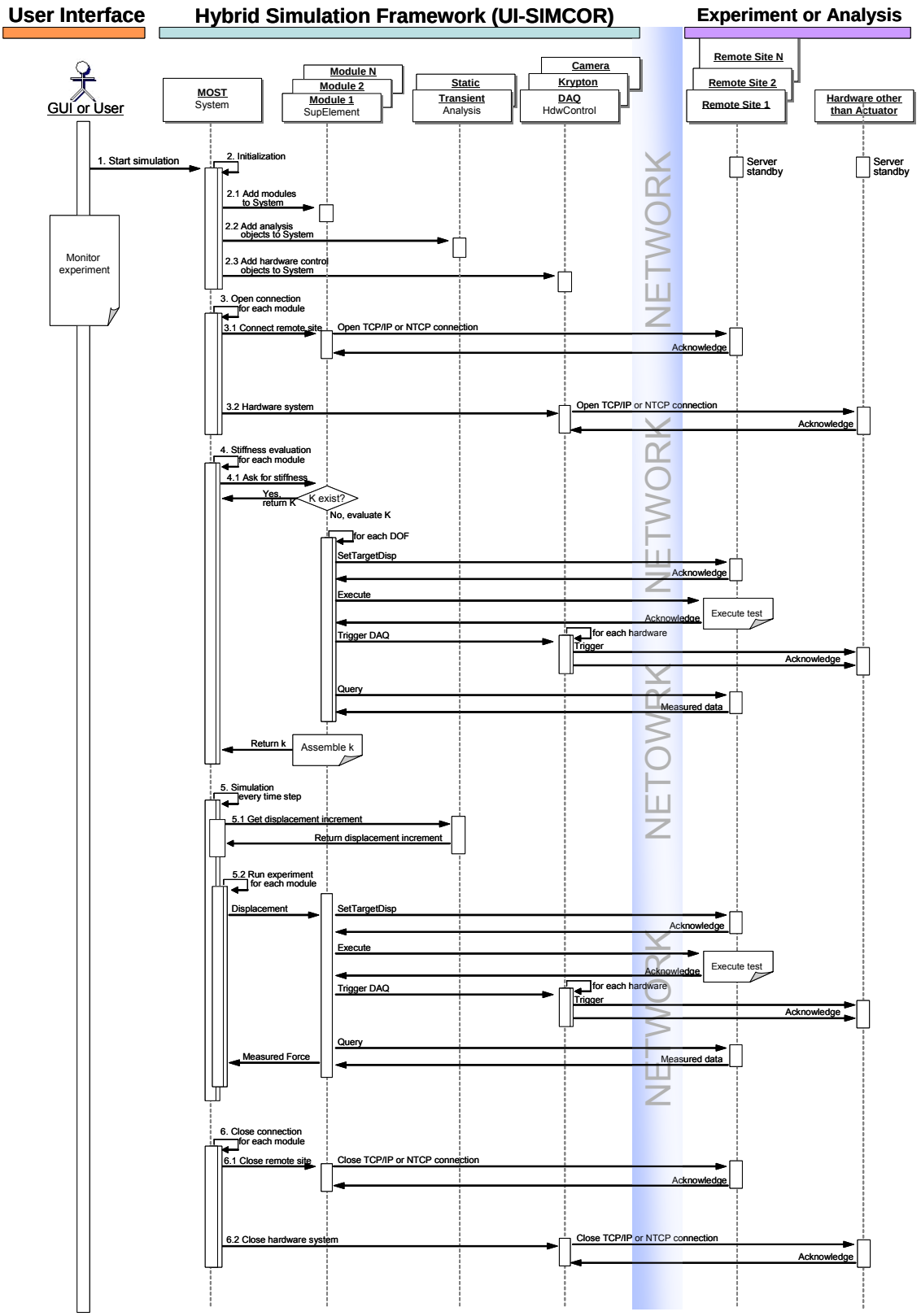
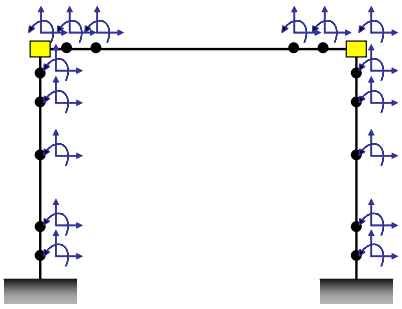


Figure 2 Flow chart of the PSD test using UI-SIMCOR

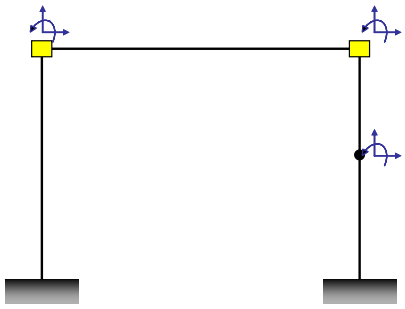
4. Sub-structuring of a Structure

4.1 Concept of Static Condensation and Sub-structuring

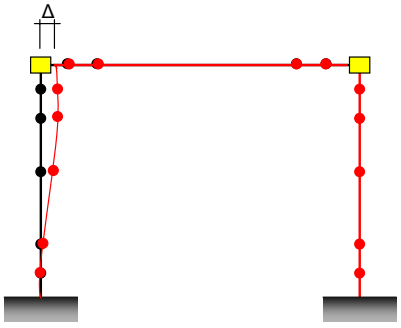
A portal frame with 16 nodes and 17 beam elements are used in this section for the purpose of illustration as shown in Figure 3 (a). Lumped masses are located at beam-column joints and ground acceleration is applied in x-direction. In the equation of motion of the frame, there will be mass and stiffness matrices with 48 by 48 elements. If we model the same frame with 3 nodes and 4 elements as shown in Figure 3(b), the mass and stiffness matrix size will be reduced to 9 by 9 but the analysis result will be identical to the model in Figure 3 (a) as long as the level of mesh refinement does not affect the analysis result. In Figure 3 (b), one node is placed in the middle of right column just to show the displacement of the node is of our interest. Even if the structure is modeled as in Figure 3 (a), the structure's mass and stiffness matrix can be also reduced using static condensation if the stiffness and mass matrices are known. If the stiffness matrix cannot be retrieved, the condensed stiffness matrix can be determined by applying a pre-specified displacement to each DOFs of interest and measuring reaction forces as shown in Figure 3 (c). This method allows us that the stiffness of a certain DOF can be calculated by applying certain displacement to the whole structure as shown in Figure 3 (c) or by applying certain displacement to segmented structure and take summation of reaction forces from each segment of structure as shown in Figure 3 (d).



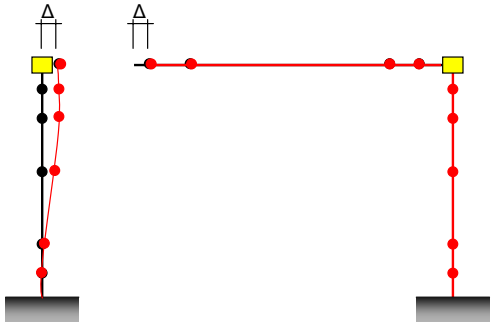
(a) Portal frame with 48 DOFs



(b) Portal frame with 9 DOFs



(c) Measurement of stiffness



(d) Measurement of stiffness from segmented structure

Figure 3 Concept of static condensation and sub-structuring

4.2 Effective DOFs for Dynamic Analysis

A dynamic analysis can be performed for a structure using reduced DOFs. The stiffness matrix of the structure with reduced DOFs can be established by applying known amount of displacement to the whole structure or segmented part of the structure.

Following simple matrix manipulation shows that certain DOFs can be condensed out from the equation of motion through static condensation. **As shown in the following derivation, remaining DOFs, or effective DOFs, are the DOFs where lumped masses are defined or the DOFs of our interest.** This is very important concept for the preparation of input file for PSD testing using UI-SIMCOR.

DOF designation

i: DOFs where mass is defined
j: interface DOFs that are of our interest
k: internal DOFs where mass is not defined and we are not interested in.

For the PSD test, we want to know displacement at *i* and *j* DOFs to impose displacement corresponding to inertial forces to experimental or static module. DOFs *k* can be condensed out since we are not interested in them.

In the equations below, alphabet letters, *M*, *0*, *u*, *F*, and *K* are matrix not scalar.

$$\begin{bmatrix} \mathbf{M}_i & & \\ & \mathbf{0}_j & \\ & & \mathbf{0}_k \end{bmatrix}\begin{bmatrix} \ddot{\mathbf{u}}_i \\ \ddot{\mathbf{u}}_j \\ \ddot{\mathbf{u}}_k \end{bmatrix}+\begin{bmatrix} \mathbf{K}_{ii} & \mathbf{K}_{ij} & \mathbf{K}_{ik} \\ \mathbf{K}_{ji} & \mathbf{K}_{jj} & \mathbf{K}_{jk} \\ \mathbf{K}_{ki} & \mathbf{K}_{kj} & \mathbf{K}_{kk} \end{bmatrix}\begin{bmatrix} \mathbf{u}_i \\ \mathbf{u}_j \\ \mathbf{u}_k \end{bmatrix}=-\begin{bmatrix} \mathbf{M}_i & & \\ & \mathbf{0}_j & \\ & & \mathbf{0}_k \end{bmatrix}\begin{bmatrix} \mathbf{l}_i \\ \mathbf{l}_j \\ \mathbf{l}_k \end{bmatrix}\left(A_g\right)$$

$$\begin{bmatrix} \mathbf{M}_i\ddot{\mathbf{u}}_i \\ \mathbf{0}_j \\ \mathbf{0}_k \end{bmatrix}+\begin{bmatrix} \mathbf{K}_{ii} & \mathbf{K}_{ij} & \mathbf{K}_{ik} \\ \mathbf{K}_{ji} & \mathbf{K}_{jj} & \mathbf{K}_{jk} \\ \mathbf{K}_{ki} & \mathbf{K}_{kj} & \mathbf{K}_{kk} \end{bmatrix}\begin{bmatrix} \mathbf{u}_i \\ \mathbf{u}_j \\ \mathbf{u}_k \end{bmatrix}=\begin{bmatrix} -\mathbf{M}_i\mathbf{l}_iA_g \\ \mathbf{0}_j \\ \mathbf{0}_k \end{bmatrix}$$

$$\begin{bmatrix} \mathbf{K}_{ii} & \mathbf{K}_{ij} & \mathbf{K}_{ik} \\ \mathbf{K}_{ji} & \mathbf{K}_{jj} & \mathbf{K}_{jk} \\ \mathbf{K}_{ki} & \mathbf{K}_{kj} & \mathbf{K}_{kk} \end{bmatrix}\begin{bmatrix} \mathbf{u}_i \\ \mathbf{u}_j \\ \mathbf{u}_k \end{bmatrix}=\begin{bmatrix} -\mathbf{M}_i\mathbf{l}_iA_g-\mathbf{M}_i\ddot{\mathbf{u}}_i \\ \mathbf{0}_j \\ \mathbf{0}_k \end{bmatrix}=\begin{bmatrix} \mathbf{F}_i \\ \mathbf{0}_j \\ \mathbf{0}_k \end{bmatrix}$$

Condense out k DOFs.

$$\begin{bmatrix} \mathbf{K}_{ii} & \mathbf{K}_{ij} & \mathbf{K}_{ik} \\ \mathbf{K}_{ji} & \mathbf{K}_{jj} & \mathbf{K}_{jk} \\ \mathbf{K}_{ki} & \mathbf{K}_{kj} & \mathbf{K}_{kk} \end{bmatrix}\begin{bmatrix} \mathbf{u}_i \\ \mathbf{u}_j \\ \mathbf{u}_k \end{bmatrix}=\begin{bmatrix} \mathbf{F}_i \\ \mathbf{0}_j \\ \mathbf{0}_k \end{bmatrix}$$

$$\left(\begin{bmatrix} \mathbf{K}_{ii} & \mathbf{K}_{ij} \\ \mathbf{K}_{ji} & \mathbf{K}_{jj} \end{bmatrix}-\begin{bmatrix} \mathbf{K}_{ik} \\ \mathbf{K}_{jk} \end{bmatrix}\left[\mathbf{K}_{kk}\right]^{-1}\begin{bmatrix} \mathbf{K}_{ki} & \mathbf{K}_{kj} \end{bmatrix}\right)\begin{bmatrix} \mathbf{u}_i \\ \mathbf{u}_j \end{bmatrix}=\begin{bmatrix} \mathbf{K}^*_{ii} & \mathbf{K}^*_{ij} \\ \mathbf{K}^*_{ji} & \mathbf{K}^*_{jj} \end{bmatrix}\begin{bmatrix} \mathbf{u}_i \\ \mathbf{u}_j \end{bmatrix}=\begin{bmatrix} \mathbf{F}_i \\ \mathbf{0}_j \end{bmatrix}$$

After rearranging terms,

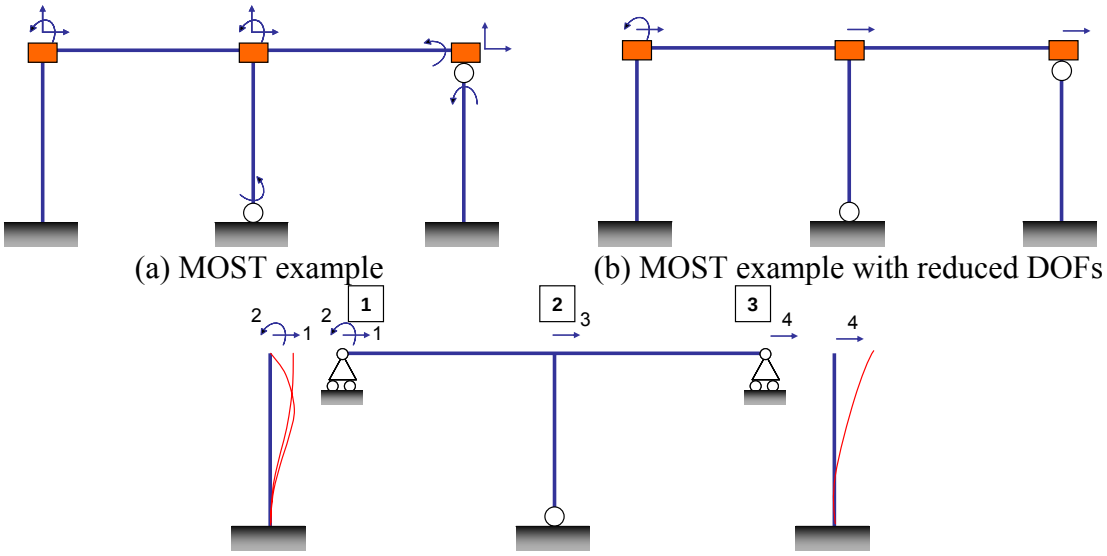
$$\begin{bmatrix} \mathbf{M}_i & \mathbf{0} \\ 0 & \mathbf{0} \end{bmatrix}\begin{bmatrix} \mathbf{a}_i \\ \mathbf{a}_j \end{bmatrix}+\begin{bmatrix} \mathbf{K}^*_{ii} & \mathbf{K}^*_{ij} \\ \mathbf{K}^*_{ji} & \mathbf{K}^*_{jj} \end{bmatrix}\begin{bmatrix} \mathbf{d}_i \\ \mathbf{d}_j \end{bmatrix}=-\begin{bmatrix} \mathbf{M}_i & \mathbf{0} \\ 0 & \mathbf{0} \end{bmatrix}\begin{bmatrix} \mathbf{l}_i \\ \mathbf{l}_j \end{bmatrix}A_g$$

or $\mathbf{M}^*\mathbf{a}^*+\mathbf{K}^*\mathbf{d}^*=-\mathbf{M}^*\mathbf{l}^*A_g$

4.3 MOST Experiment

As described in the previous section, the equation of motion of a structure can be established using only effective DOFs, i.e., DOFs where lumped masses are defined or DOFs of our interest.

The MOST experiment example consists of two portal frames as given in Figure 4 (a). The stiffness matrix of the structure will be a size of 11 by 11 with DOFs in Figure 4 (a). Assuming that there are no axial deformations in columns, and we are not interested in the rotation of hinge connections and rotation of mid-column-beam connection, the number of DOFs can be reduced to 4 as shown in Figure 4 (b). The rotational DOF of the left column is of our interest since the column will be tested using two DOFs on top. All the translational DOFs should be included since mass is defined in the DOFs and inertial forces should be applied. Also it is assumed that the lumped masses have x-directional component only. If the lumped mass is significantly large in rotational direction, then the rotational DOFs should be included in Figure 4 (b). Figure 4 (c) shows subdivided structure into three parts, left column with two DOFs, mid-column and beam with four DOFs, and right column with one DOF.



(a) MOST example (b) MOST example with reduced DOFs

(c) Subdivided structure

Figure 4 Effective DOFs of the MOST example

5. Static Analysis Module Interface

In this distribution, FEDEAS Lab, ZEUS-NL, OpenSees, ABAQUS, OpenFresco, and NHCP Simulation Server are included as static analysis modules. The static analysis modules need to take displacements from simulation coordinator and give reaction forces to the simulation coordinator. All these communications run through communication protocol. Thus, it was necessary to develop an interface module for these analysis softwares.

FEDEAS Lab
FEDEAS Lab was not need to be modified to work as a static analysis module since input and out can be easily managed in MATLAB. A few additional scripts need to be written to connect to UI-SIMCOR and give displacement and take forces from FEDEAS Lab. NEES_FL_LabView2.m plays this role using LabVIEW2 protocol. In case when it is necessary to communicate through NEESpop using NTCP for Matlab, NEES_FL_NTCP.m can be used. But NTCP for Matlab requires several prerequisite applications.

ZEUS-NL
Original version of ZEUS-NL was modified and recompiled. The modified solver, NEES_Solver.exe, takes displacement input from console and makes reaction force output into a file in each step. NEES-SAM, which stands for Static Analysis Module for NEESgrid, gives displacement to the modified ZEUS-NL and reads the force output file. NEES-SAM acts as an interface between UI-SIMCOR and ZEUS-NL. There are three versions of NEES-SAM for TCP-IP, LabVIEW1, and LabVIEW2 protocols. The protocols will be explained in detail in Section 6.

OpenSees
OpenSees was also modified to generate an output file for each step. Among the source code files, NodeRecorder.cpp was modified. NEES-SAM also works as an interface between UI-SIMCOR and OpenSees.

ABAQUS
It is not possible to modify the ABAQUS as it is commercial software. So, restart feature in ABAQUS is utilized to use ABAQUS as a static analysis module. A MATLAB scripts are developed to connect to UI-SIMCOR and give displacement to and take forces from ABAQUS. NEES_Abaqus_LabView2.m plays this role using LabVIEW2 protocol. This is very similar to FEDEAS Lab static analysis module interface, NEES_FL_NTCP.m.

OpenFresco
Open Framework for Experimental Setup and Control (OpenFresco) is a software framework intended to facilitate and help standardize the local or geographically-distributed deployment of hybrid simulation and developed by UCB (Schellenberg et. al., 2006). OpenFresco can acts as an interface between experimental hardware and main simulation coordinator. In addition, it also has a functionality to simulate experimental

hardware so that the PSD simulation can be verified without experimental setup. The OpenFresco 2.0 was distributed with Matlab-OpenFresco examples and OpenSees-OpenFresco examples. As UI-SimCor is written in Matlab, the Matlab-OpenFresco example was utilized so that OpenFresco can work with UI-SimCor. OpenFresco uses TCP-IP connection to communicate with simulation coordinator written in any platform such as Matlab, UI-SimCor, or OpenSees. The communication protocol between MATLAB and OpenFresco is provided by Schellenberg et. al., (2006) in MEX file format (TCPSocket.mexw32). This file is combined with UI-SIMCOR for hybrid simulation. Currently, only 1-DOF simulation case is supported in UI-SimCor. The protocol is referred as OpenFresco1D protocol in UI-SimCor. The original version of OpenFresco provides two- and three-actuator cases, and also generic element for generic FEM application. This extension will be combined with the next version of UI-SIMCOR.

NHCP Simulation Server

The NEES Hybrid Simulation Protocol (NHCP) is at the early stage of development. As a pilot example, NEESit provided a simple example for which OpenSSL is used to encrypt communication data and data for very simple system (1-DOF) can be transferred. Currently, NHCP can be used for numerical simulation, and MiniMOST 1 and 2 in UIUC or SDSC. For numerical simulation, only linear 1-DOF case is supported by NHCP Simulation Server. A generalized version of NHCP will be implemented in UI-SIMCOR when the development of NHCP in NEESit is completed.

6. Protocol Specification

6.1 NEESgrid Teleoperation Control Protocol (NTCP)

6.1.1 Background and introduction

NTCP is the first communication protocol for the hybrid simulation developed by NEESit. Recently, NEESit has been developing new communication protocol, NHCP, but it is not officially released yet. The further explanation about NHCP will be given latter.

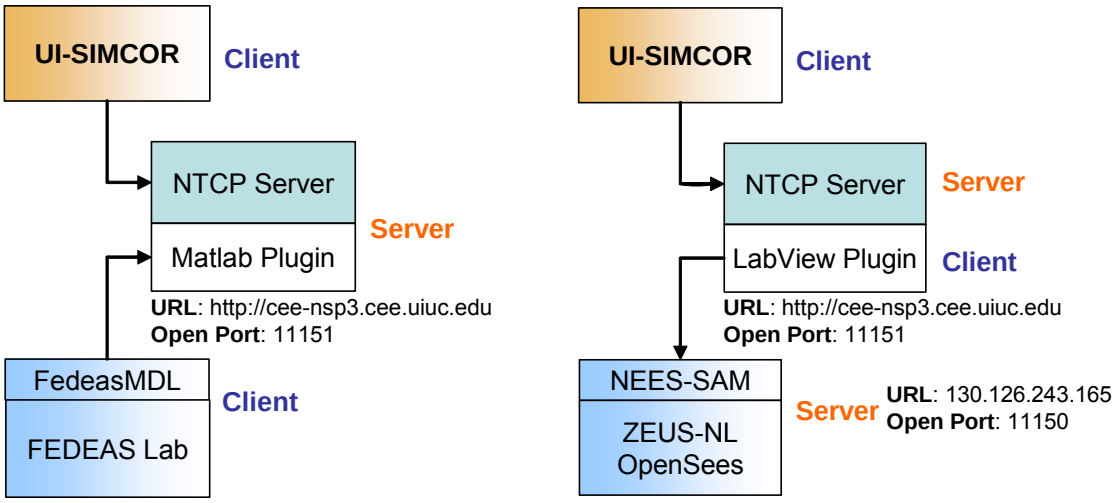
UI-SIMCOR uses the *NTCP Toolbox for MATLAB* developed by NEESit. The setup procedure of NTCP is very complicated compared to other protocols. The detailed explanation of NTCP including *NTCP Toolbox for MATLAB* can be found in NEESit website (http://it.nees.org). In this section, a simple explanation how NTCP works with UI-SIMCOR will be given.

6.1.2 NTCP server connection with UI-SIMCOR

Two types of plugin are used for the NTCP server to connect to the backend client, such as FEDEAS Lab, ZEUS-NL, OpenSees, or experimental equipment (Currently, OpenFresco and NHCP Simulation Server do not support the NTCP). The plugins are MATLAB plugin and LabVIEW plugin.

As FEDEAS Lab is running on the MATLAB, the connection to FEDEAS Lab is made using MATLAB plugin. For the communication through MATLAB plugin, NTCP server acts as a server for both ends. Thus the NTCP server waits for the connection from UI-SIMCOR and FEDEAS Lab with specified open ports. In the configuration of UI-SIMCOR and FEDEAS Lab, the URL and open port number of NTCP server should be given. Both ends, UI-SIMCOR and FEDEAS Lab, connect to NTCP server using same port number. Figure 5 (a) shows the connection diagram. The port number and URL in the figure are just example.

ZEUS-NL, OpenSees, and test equipments use LabVIEW plugin to connect to the NTCP server. As opposed to the MATLAB plugin, NTPC server act as a server for the connection with UI-SIMCOR and act as a client for the connection to the backend, Figure 5(b). Thus, there is a URL and port number of NTCP server in UI-SIMCOR, and there is a URL and port number of backend when the NTCP server runs.



(a) Connection through MATLAB plugin (b) Connection through LabVIEW plugin

Figure 5 Connection diagram of NTCP server using MATLAB and LabVIEW plugin

6.2 TCP/IP Protocol

6.2.1 Background and introduction

TCP connection with binary data format is used for TCP/IP protocol. For the TCP connection with remote site, *Instrument Control Toolbox* of MATLAB is used. This toolbox is a collection of M-file functions build on the MATLAB technical computing environment. The toolbox provides a framework for communicating with instruments that support the GPIB interface, the VISA standard, and the TCP/IP and UDP protocols. The transferring data can be binary (numerical) or text. The transfer can be synchronous and block the MATLAB command line, or asynchronous and allow access to the MATLAB command line. More details about *Instrument Control Toolbox* can be found in the manual of MATLAB or MATHWORKS website (www.mathworks.com).

6.2.2 Basic sequence of commands

A typical sequence of commands from TCP/IP protocol to the control system looks like this:

1. initialize
    1) create TCP/IP communication object
    2) set parameters
2. open
    1) connect interface to remote site
    2) send initialize data to remote site
    3) receive acknowledgement from remote site
3. loop N times:

1) propose
2) query

4. close
    1) send closing data to remote site
    2) disconnect interface object from remote site

6.2.3 Detailed syntax of each step

initialize

Syntax:

```
Comm_obj = tcpip(IP, PORT);                    : to create TCP/IP object
set(Comm_obj, 'PropertyName', PropertyValue);  : to set parameters
```

where `Comm_obj` is TCP/IP communication object returned from TCP connection. `IP` and `PORT` are IP address and port number of remote site, respectively. `PropertyName` and `PropertyValue` are a property name for `Comm_obj` and a property value supported by `PropertyName`, respectively. For UI-SIMCOR, `PropertyName` and `PropertyValue` for initialization process are set to `'InputBufferSize'`, and `1024×100`, respectively.

For example:

```
Comm_obj = tcpip(127.0.0.1, 11997);
Set(Comm_obj, 'InputBufferSize', 1024×100);
```

open

Syntax:

```
fopen(Comm_obj);            to connect interface object to remote site
fwrite(Comm_obj, iniData); to send initialize data to remote site
fread(Comm_obj, size);      to receive acknowledgement data from remote site
```

For example:

```
fopen(Comm_obj);
fwrite(Comm_obj, 500);      set total number of simulation steps
fread(Comm_obj, 4);         read 4 bytes of data
```

propose

Syntax:

`fwrite(Comm_obj, T_DISP);` to write binary data to remote site

where `T_DISP` is target displacement calculated from UI-SIMCOR.

query

Syntax:

`fread(Comm_obj, size);` to read `size` bytes binary data from remote site

close

Syntax:

`fwrite(Comm_obj, closeData);` to send closing data to remote site
`fclose(Comm_obj);` to disconnect interface object from remote site

6.3 LabVIEW1 and LabVIEW2 Protocols for NTCP Server

Many users of NTCP experienced slow communication and a little cumbersome setup process. So, LabVIEW1 and 2 protocols use direct connection between coordinator and remote sites without NEESpop. The original version of LabVIEW1 protocol was written for the communication between NEESPop and LabVIEW-controlled hardware. The communication is basically conducted in ASCII format data. In UI-SimCor, the specific ASCII-based communication is referred as LabVIEW1 or LabVIEW2. But it does not necessarily involve LabVIEW software. These protocols are a simple ASCII format designed for easy parsing and communications occur over a single TCP connection. This section is based on the document about LabVIEW NTCP plugin which can be found in NEESit website (http://it.nees.org/document/pdf/TR-2004-58.pdf).

6.3.1 Background and introduction

Any system wishing to use this protocol must be capable of having a process open and listen on a TCP port (i.e., have threading, or some equivalent form of multitasking and interprocess communications). All messages are tab-delimited ASCII, on a single line, variable length (Newline is the message delimiter) and should be human-readable. The protocol should, as much as possible, simply act as a serialization layer, with all the work being done on the client side. This means less assumption about client functionality, and higher implementation flexibility. As a side benefit, simper protocol code reduces complexity and the number of bugs. Any language that can host a TCP connection and parse string can be a full-fledged NTCP controller. This opens several doors to lightweight control of small devices such as pan-tilt-zoom camera bases. Transaction ID is included in every message, so that the client side can be asynchronous and multithreaded (This is how the LabVIEW control code was implemented). LabVIEW1 protocol has *Propose-Query-Execute-Query* structure whereas LabVIEW2 has *Propose-Query* structure.

6.3.2 Basic sequence of commands

The normal sequence of commands from LabVIEW protocol to the control system looks like this:

1. open-session
2. set-parameter
3. get-parameter
4. loop N times:
    1) propose
    2) execute

3) get-control-point
5. close-session

where steps 2 and 3 are semi-optional, and depend on the program running LabVIEW protocol (This is sometimes called an 'client' or 'simulation coordinator', depending on the context).

6.3.3 Detailed syntax for each verb

open-session

Syntax:
```
open-session TransactionID {parameter} {parameter}
```

This can optionally initialize hardware or do other system-specific work as required. This should be the very first command of a connection. The parameters are control-system-specific, meaning you can use this for whatever you need – they are optional. The LabVIEW implementation ignores the transaction ID and any parameters sent.

close-session

This mirrors open-session. Currently performs no work, but can be used as required. Should be the last command received in an LabVIEW protocol session.

propose

Syntax:
```
propose TransactionID ControlPoint GeomType ParameterType Parameter
ControlPoint GeomType ParameterType Parameter …
```

where there can be zero to twelve parameters. The spec also allows zero parameters, for implied commands based on the control point name. `GeomType` mirros the NTCP specification, and is a single character: `x`, `y`, or `z`. `ParamterType` also mirrors the specification, and can be: `displacement`, `force`, `rotation`, or `moment`. `Parameter` is simple a scalar floating-point number.

For example:
```
propose Transaction0 ANCO-table x force 0.3 x displacement 3.1 y rotation
180.1
```

execute

Syntax:
```
execute TransactionID
```

This simply triggers execution of a previously-accepted proposal. Obviously, the transaction ID must have been both proposal and accepted for this to be valid. The control system should not return until the execution is complete.

cancel

Syntax:

```
cancel TransactionID
```

This command cancels a pending command, usually due to a proposal being rejected by another control system somewhere else and the plugin throw an exception. This should return OK if the transaction was canceled successfully.

get-control-point

Syntax:

```
get-control-point TransactionID ControlPoint
```

where the transaction ID is usually ignored, but required for consistent parsing. The return format has a variable number of parameters, depending on what the given control point supports. Mirroring the propose syntax, it returns to up to twelve triplets of `GeomType ParamType Paramter` with the same types as 'propose' above, e.g., 'x displacement 1.414'

For example:

```
get-control-point DummyTransactionID003 ANCO
```

replies

```
OK 0 DummyTransactionID003 x displacement 0.0 x force -0.113 y rotation
0.0 z rotation 0.0
```

This is an often-called method and should be asynchronous of the propose/execute logic if possible. In the LabVIEW implementation, a separate loop in the control program handles these requests and returns instant DAQ readings, enabling real-time data as a move happens. It uses a LabVIEW semaphore to mark the TCP send as a critical section, so that the various threads do not collide in communicating with NTCP server.

get-parameter

Syntax:

```
get-parameter TransactionID ParamName
```

Return syntax:

```
OK 0 ParamName Parameter
```

This is mainly used by the MATLAB code to pass simulation parameters around.

set-parameter

Syntax:

```
set-parameter TransactionID ParamName Parameter
```

This is the mirror of `get-parameter`. The plugin sends whatever it gets, and LabVIEW duly ignores it with an OK response.

6.4 OpenFresco1D Protocol

6.4.1 Background and introduction

OpenFresco1D protocol is used for OpenFresco module. OpenFresco is a software framework intended to facilitate and help standardize the local or geographically-distributed deployment of hybrid simulation and developed by UCB (Schellenberg et. al., 2006). OpenFresco cannot perform hybrid simulations by itself, it simply mediates in a modular and highly structured manner instructions between a host (client) numerical simulation computer and laboratory equipment. It uses TCP connection to connect with simulation coordinator (e.g., UI-SIMCOR). The communication protocol between MATLAB and OpenFresco is also provided by Schellenberg et. al., (2006) in MEX file format (TCPSocket.mexw32).

The MEX file is dependent on the MATLAB version. In the UI-SIMCOR there are three different MEX files, i.e., TCPSocket_v65.mex, TCPSocket_R2006a.mexw32, and TCPSocket_R2006b.mexw32 for MATLAB v6.5, R2006a, and R2006b, respectively. The default MEX file for OpenFresco1D protocol sets to MATLAB version R2006b. If user wants to MEX file for MATLAB v6.5 or MATLAB R2006a, change file name from TCPSocket_v65.mex or TCPSocket_R2006a.mexw32 into TCPSocket.mex or TCPSocket.mexw32. If a difference version of MATLAB is used, the user needs to create a new MEX file based on the User Manual for OpenFresco (Schellenberg et. al., 2006).

The MEX file developed for the communication between MATLAB and OpenFresco is utilized in UI-SIMCOR for communication with OpenFresco. Currently, only 1-DOF simulation case is supported even though OpenFresco provides two- and three-actuator cases, and generic element which will be implemented in the next version of UI-SIMCOR. This section is based on the User Manual for OpenFresco, so more details about OpenFresco can be found in the OpenFresco project page of NEESit (https://neesforge.nees.org/projects/openfresco).

6.4.2 Usage of OpenFrescoID protocol

setup connection

Syntax:

```
socketID = TCPSocket ('openConnection', PORT_OpenFresco, IP_OpenFresco);
```

where `socketID` is ID for connection, `'openConnection'` for open action, and `PORT_OpenFresco` and `IP_OpenFresco` are port number and IP address for OpenFresco, respectively.

set data sizes for remote site

Syntax:

```
TCPSocket ('sendData', socketID, dataSizes, 11);
```

where `'sendData'` for sending data to OpenFresco. `dataSizes` is size of data which will be sent to OpenFresco. For 1-DOF system `dataSizes = int32([1 0 0 0 0, 0 0 0 1 0, dataSize]);` where `dataSize = 2 .`

send target responses to remote site

Syntax:

```
TCPSocket('sendData', socketID, sData, dataSize);
```

where `sData` is for target displacement of size 1 × 2. `sData(1) = 3` for `'sendData'` command and `sData(2)` is target displacement which was sent from UI-SIMCOR. `dataSize` is size of `sDate`, i.e., 2.

get measured restoring force

Syntax:

```
TCPSocket('sendData', socketID, sData, dataSize);
rData = TCPSocket('recvData', socketID, dataSize);
```

where `sData` is scalar value of 10 for query action, `dataSize` is 2 which was defined during 'set data sizes for remote site', rData is measured restoring force received from OpenFresco. UI-SIMCOR assumes that the measured displacement is same with the target displacement.

disconnect from remote site

Syntax:

```
TCPSocket('sendData', SocketID, sData, dataSize);
TCPSocket('closeConnection', socketID);
```

where `sData` is a scalar value of 99 for close action, `dataSize` is 2 which was defined during 'set data sizes for remote site'.

6.5 NEES Hybrid Communication Protocol (NHCP)

6.5.1 Background and introduction

Previous communication protocol of NEESit (i. e., NTCP) is designed for slow tests, over unreliable networks, spanning one or more laboratories. Indeed, it has been used successfully in several of these, and researchers continue to use it. NEESit has been reworking NTCP such that it can be used for fast distributed tests. In particular, one proposed experiment, they are using as a goal is 75 Hz over a 500 km link.

NEESit are not going toe try and address fast hybrid tests that run in hard real time, instead they will focus on distributed tests, both slow and 'fast', attempting to run as fast as possible.

One area where NEESit can contribute is streaming data. NEESit have an existing system based on the Create Date Turbine that works well for data, video and audio. NEESit plans

on implementing an interface to the turbine for streaming commands, responses, events and other experimental data for observers and participants.

Security is another area where NEESit can contribute. The framework will have authentication, authorization and hooks or tools to administer permissions. GridAuth (http://www.gridauth.com/), Kerberos (http://web.mit.edu/kerberos/), and JAAS (http://java.sun.com/products/jaas/) are all intriguing here. Based on initial results and feedback from the Denver meeting (http://it.nees.org/weblog/hybridsim/?p=3), OpenSSL (http://www.openssl.org/) are used for TCP/IP, both plaintext and encrypted. OpenSSL allows to leverage the considerable investments in code, infrastructure and hardware acceleration that others have made, with confidence that the underlying code is reliable and well-tested. Most of part of this section is based on the technical documents of NEESit which can be found in http://it.nees.org/weblog/hybridsim/?p=67.

6.5.2 Abstractions and paradigms

The various systems differ in how they split up the work. Here is a pretty common setup from a physical viewpoint.

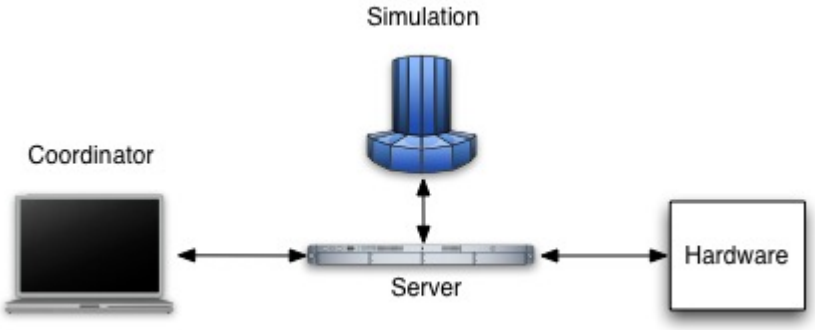


Figure 6 Common setup of hybrid simulation

The functional view looks like as follow.

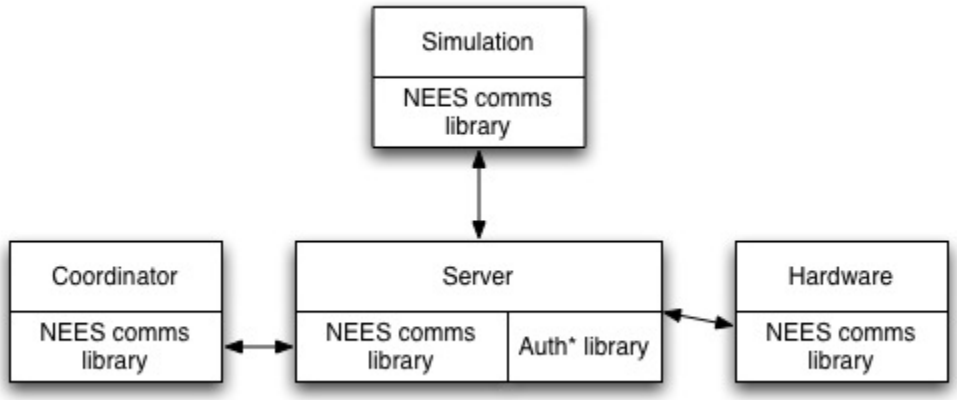


Figure 7 Functional view of hybrid simulation

Here is a diagram of the second design. Block in green represent TCP/IP server process, where the program in question is responsible for accepting a TCP/IP connection, and light brown represents the corresponding TCP/IP client. This is revised quite a bit as follow.

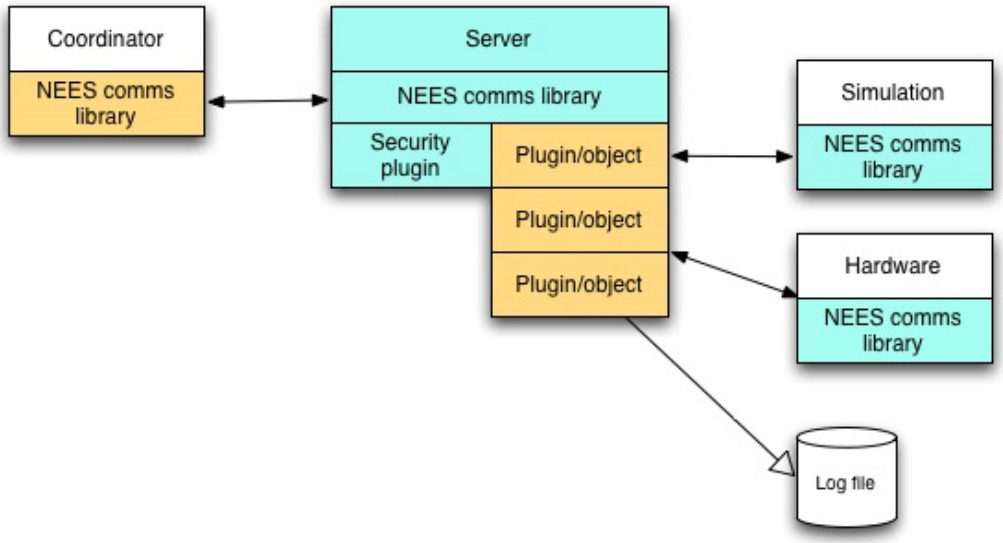


Figure 8 Functional view of hybrid simulation using NHCP

The major difference is that the server is back to running multiple plugins. As before, a coordinator can and will talk to multiple servers (one per site, probably) but each server will load and run multiple plugins.

This is worth discussing a bit, both for how it came about and also for the consequences of the design. First off, the server is now more event-driven, with messages arriving and departing all the time, from given displacement. This is sent to all plugins, starting with the security plugin. Each plugin can look at the command, source and (optional) destination and decide if they need to act or not. It has an Observer plugin that, as pictured, generates no messages but logs all to disk. In the example, the control plugin would take the command, move the hardware (or simulation), compute reaction forces, and then generate a new MSG_REACTION which the server would send to the coordinator, and also all the plugins.

This enables a number of nice things, and makes the plugins' interface simpler, but requires a bit more of the server to keep it from slowing as the number of communicating processes increases. To wit;

1. Each plugin runs in its own thread.
2. Each message queue (to/from plugin, to/from coordinator) is a thread-safe queue of fixed maximum length. If a plugin gets too far behind, the server will drop messages rather than wait, generating a critical error callback to the plugin upon doing so. This keeps a slow plugin from rate-limiting the server.
3. The server has to decide whether a plugin running or not if the connection to the

coordinator is lost. Normally, NHCP would just terminate the plugins and reset, but it needs to consider error handling. Did the coordinator crash? Was it killed? Or was the network temporarily damaged? Since NHCP can not tell from within the server, its generates a critical error callback and lets the plugins do whatever error handling is required. The coordinator can reconnect and resume when able. If the coordinator logs out and unloads the plugins, then they are terminated in the normal fashion.

4. The server has a simple interface (MSG_QUERY, LOAD and UNLOAD) for dynamic discovery and plugin management.

There are a number of benefits to this design;

1. Server configuration is greatly reduced. In most uses, there needs be only one server running, on a single well-known TCP port. Coordinators can simply connect, login, and then load the plugins required for their test. This compares well to the effort required to configure NTCP.
2. All plugins see all messages, making possible things like the observer plugin that can be used for monitoring, logging, database back ends and eventually RBNB, all transparently.
3. Users can load multiple instances of a single plugin into the server, and configure them on the fly to do different tasks. For example, SDSC will use the NTCP/ASCII plugin twice, to connect to MiniMOST 1 and 2. This is accomplished by loading the plugin, then using the new MSG_SET_INSTANCE_NAME and MSG_SET to configure the backend and 'instance' (human-readable label) name. That way, the Observer can log commands in an intelligible format, e.g. 'Coordinator 1 tells M1 to move to 0.01m'.
4. The server handles addressing. All plugin instances get a unique numeric ID, as do all coordinators. These are returned to the coordinator after loading a plugin, so that the coordinator can send messages to specific places. For example, user can send different displacements to the two mini-mosts, so that they both do the move correctly, and when they generate reaction force messages the coordinator will know their origin.
5. The server actually has a simpler job now. It manages plugin loading, loads the security plugin first, and then mainly spends its time checking messages queues and moving them around as required. All the heavy lifting is done in plugins running in their own thread.
6. The plugin authors have a simpler job. There are less than five callbacks to implement, and then they can focus on handling and generating messages. They can use whatever method of communication is easiest; including our new OpenSSL wrapper classes if they like.

Looking at a more detailed picture, let's add the data turbine and authorization/authentication bits.

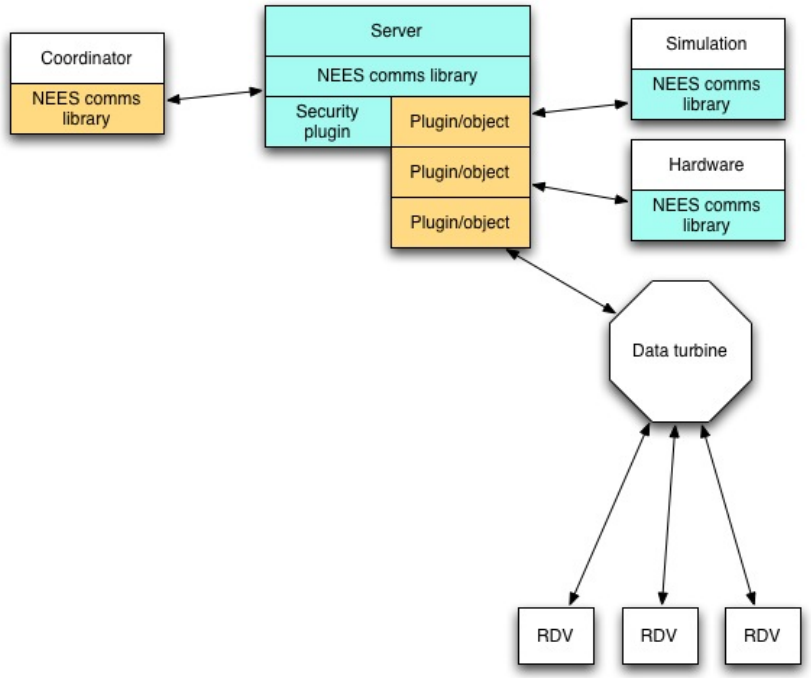


Figure 9 Detailed functional view of hybrid simulation using NHCP

Security

There are several things to consider here;

1. Message integrity - was the data corrupted, either accidentally or deliberately?
2. Authenticity - are you talking to the process you expected, or the man in the middle?
3. Authorization - is user J allowed to control hardware X?
4. Encryption - is you have proprietary (e.g. commercial) data, you might want to prevent against interception.

For solution, NEESit proposes using a tiered solution;

1. OpenSSL for communications
   a. Plain socket mode (default, fastest, simple)
   b. Message digests, plaintext - this addresses #1
   c. Encrypted with digests
2. External username/password mechanism TBD. There are many possibilities here (kerberos, PAM, JAAS, Gridauth, Globus, etc, etc).

The use of OpenSSL does complicate the development and compilation a bit, but there are many offsetting factors. It's a well-established standard, cross-platform, stable and can be accelerated with crypto cards if desired. If user employ server and client certificates, they can ensure secure communications with minimal overhead, both runtime and administrative.

6.5.3 MEX file

MEX stands for MATLAB Executable, MEX files are dynamically linked subroutines produced from C/C++ or Fortran source code that, when compiled, can be run from within MATLAB in the same way as MATLAB M-files or built-in functions. The external interface functions of MATLAB manual provide functionality to transfer data between MEX-files and MATLAB, and the ability to call MATLAB functions from C/C++ or Fortran code. The main reasons to write a MEX-file are;

1. The ability to call large existing C/C++ or Fortran routines directly from MATLAB without having to rewrite them as M-files.
2. Speed; user can rewrite bottleneck computations (like for-loops) as a MEX-file for efficiency.

The source code for a MEX-file consists of two distinct parts;

1. A computational routine that contains the code for performing the computations that you want implemented in the MEX-file. Computations can be numerical computations as well as inputting and outputting data.
2. A gateway routine that interfaces the computational routine with MATLAB by the entry point `mexFunction` and its parameters `prhs`, `nrhs`, `plhs`, `nlhs`, where `prhs` is an array of right-hand input arguments, `nrhs` is the number of right-hand input arguments, `plhs` is an array of left-hand output arguments, and `nlhs` is the number of left-hand output arguments. The gateway calls the computational routine as a subroutine.

In the gateway routine, user can access the data in the `mxArray` structure and then manipulate this data in your C/C++ computational subroutine. For example, the expression `mxGetPr(prhs[0])` returns a pointer of type double * to the real data in the `mxArray` pointed to by `prhs[0]`. User can then use this pointer like any other pointer of type double * in C/C++. After calling user's C/C++ computational routine from the gateway, user can set a pointer of type `mxArray` to the data it returns. MATLAB is then able to recognize the output from your computational routine as the output from the MEX-file.

The following C/C++ MEX cycle figure shows how inputs enter a MEX file, what functions the gateway routine performs, and how outputs return to MATLAB.

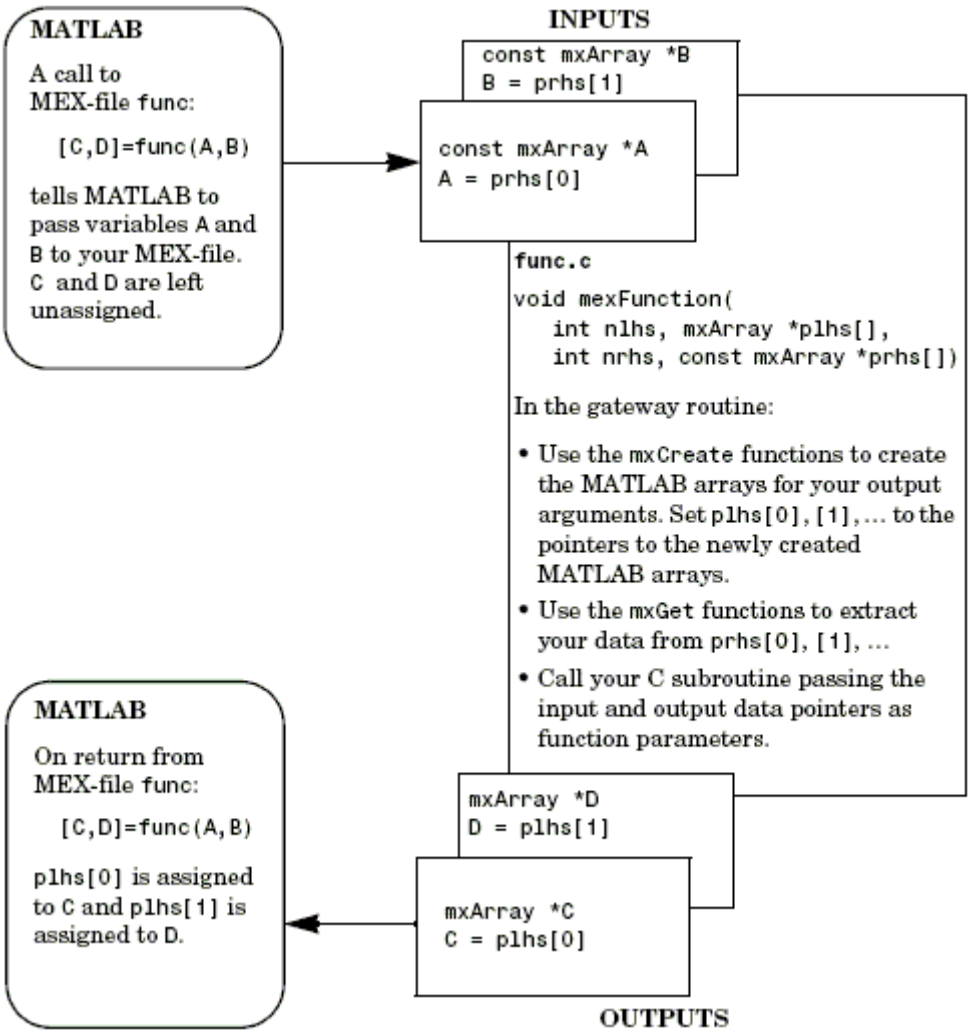

MATLAB
A call to MEX-file func:
[C,D]=func(A,B)
tells MATLAB to pass variables A and B to your MEX-file. C and D are left unassigned.
INPUTS
const mxArray *B
B = prhs[1]
const mxArray *A
A = prhs[0]
func.c
void mexFunction(
int nlhs, mxArray *plhs[],
int nrhs, const mxArray *prhs[])
In the gateway routine:
• Use the mxCreate functions to create the MATLAB arrays for your output arguments. Set plhs[0], [1], ... to the pointers to the newly created MATLAB arrays.
• Use the mxGet functions to extract your data from prhs[0], [1], ...
• Call your C subroutine passing the input and output data pointers as function parameters.
MATLAB
On return from MEX-file func:
[C,D]=func(A,B)
plhs[0] is assigned to C and plhs[1] is assigned to D.
mxArray *D
D = plhs[1]
mxArray *C
C = plhs[0]
OUTPUTS

Figure 10 C/C++ MEX cycle

In this figure a call to the MEX file named `func` of the form `[C, D] = func(A,B)` tells MATLAB to pass variables `A` and `B` to user's MEX-file. `C` and `D` are left unassigned.

The `func.c` gateway routine uses the `mxCreate` function to create the MATLAB arrays for your output arguments. It sets `plhs[0]`, `[1]`, `...` to the pointers to the newly created MATLAB arrays. It uses the `mxGet` functions to extract user's data from `prhs[0]`, `[1]`, `...` Finally, it calls C/C++ subroutine, passing the input and output data pointers as function parameters.

On return to MATLAB, `plhs[0]` is assigned to `C` and `plhs[1]` is assigned to `D`.

The two components of the MEX-file may be separate or combined. In either case, the files must contain the `#include "mex.h"` header so that the entry point and interface routines are declared properly. The name of the gateway routine must always be `mexFunction` and must contain these parameters.

```
void mexFunction(int nlhs, mxArray *plhs[], int nrhs, const mxArray
*prhs[]){
         /* more C/C++ code ... */
        }
```

The parameters `nlhs` and `nrhs` contain the number of left- and right-hand arguments with which the MEX file is invoked. In the syntax of the MATLAB language, functions have the general form of

```
[a,b,c,...] = fun(d,e,f,...)
```

where the ellipsis `(...)` denotes additional terms of the same format. The `a,b,c,...` are left-hand arguments and the `d,e,f,...` are right-hand arguments.

The parameters `plhs` and `prhs` are vectors that contain pointers to the left- and right-hand arguments of the MEX file. Note that both are declared as containing type `mxArray *`, which means that the variables pointed at are MATLAB arrays. `prhs` is a length `nrhs` array of pointers to the right-hand side inputs to the MEX-file, and `plhs` is a length `nlhs` array that contains pointers to the left-hand side outputs that your function generates.

For example, if user invokes a MEX file from the MATLAB workspace with the command `x = fun(y,z);` the MATLAB interpreter calls `mexFunction` with the following arguments:

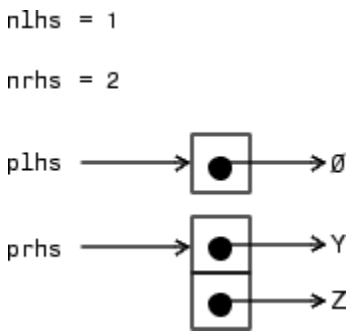


Figure 11 Relationship between MATLAB and C/C++ variables

`plhs` is a 1-element C/C++ array where the single element is a null pointer. `prhs` is a 2-element C/C++ array where the first element is a pointer to an `mxArray` named Y and the second element is a pointer to an `mxArray` named Z.

The parameter `plhs` points at nothing because the output `x` is not created until the subroutine executes. It is the responsibility of the gateway routine to create an output array and to set a pointer to that array in `plhs[0]`. If `plhs[0]` is left unassigned, MATLAB prints a warning message stating that no output has been assigned.

More details about MEX file can be found at MATHWORKS website (www.mathworks.com).

6.5.4 NHCP DLL file

The NHCP is implemented in UI-SIMCOR by modifying the existing demo files of NHCP. There are four demo files in NHCP, i.e., `simdemo.cpp`, `m1driver.cpp`, `m2driver.cpp`, `baronDemo.cpp`. `simdemo.cpp` is for the simulation demo, `m1driver.cpp` and `m2driver.cpp` are for MiniMOST 1 and 2, respectively.
These four files are combined into one MEX file, i.e, NHCP.dll for UI-SIMCOR. If file is compiled within MATLAB, then the file will depend on the MATLAB version, so we compiled the source code within Microsoft Visual Studio 2005 to make Dynamically Linked Library (DLL) file. NCS (server for NHCP) and SimServer (simulation server for NHCP) are also modified to receive the port number for NCS and port number and stiffness for SimServer, respectively.

6.5.5 Usage of NHCP

UI-SIMCOR will call NHCP.dll file if NHCP protocol is used for hybrid simulation. Currently, there are three modes in NHCP, i.e., simulation mode with linear 1-DOF system, MiniMOST 1 and 2 modes. NEESit has not generalized the NHCP, so NHCP for UI-SIMCOR is restricted for a special case as mentioned in the above. However, when NEESit releases the generalized NHCP, it will be implemented into UI-SIMCOR.

There are three actions in each mode of NHCP, i.e., 'open', 'run', and 'close'. During 'open' action, UI-SIMCOR is connected with NHCP server (i.e., NCS) through OpenSSL connection and NCS is connected with simulation server (i.e., SimServer) for simulation mode or computer for Mini MOST 1 or 2 using TCP connection. During 'run' actions, propose target displacement and query measurement are conducted simultaneously. Processes for 'execute' or 'query' used in NTCP or LabVIEW protocol are not required. Finally, the UI-SIMCOR and NCS are disconnected from NCS and SimServer (or computer for MiniMOST 1 or 2), respectively during 'close' action.

open

Syntax:

```
NHCP(NHCPMode, 'open', IP_NCS, PORT_NCS, IP_SERVER, PORT_SERVER,
STIFFNESS_SIM)
```

where `NHCPMode` is one of `Sim1D` for simulation case with linear 1-DOF system, `MM1`, `MM2` for MiniMOST 1 and 2, respectively.
`'open'` command for open action, and `IP_NCS`, `PORT_NCS`, `IP_SERVER`, `PORT_SERVER` are IP address and port number for NCS and simulation server for simulation case with linear 1-DOF system, computer for MiniMOST 1, and computer for Mini MOST 2, respectively. Finally, `STIFFNESS_SIM` is the stiffness of simulation case and required only when NHCP is used for simulation case (i.e., `NHCPMode` is `Sim1D`). It does not include units and units are depends on the simulation coordinator (i.e., UI-SIMCOR). All of input variable for NHCP should be bracketed by ''. For `'open'` action, there is no return value from NHCP protocol. Instead if there are errors during connection to NCS and SimServer (or MiniMOST 1 and 2), there are errors messages in the NCS command window.

For example:

```
NHCP('Sim1D', 'open', '127.0.0.1', '11997', '127.0.0.1', '11998',
'1000');
NHCP('MM1', 'open', '127.0.0.1', '11997', '127.0.0.1', '11998');
```

run

Syntax:

For `Sim1D` and `MM1` modes

```
[M_FORC] = NHCP(NHCPMode, 'run', T_DISP);
```

For `MM1` mode

```
[M_DISP, M_ROT, M_FORC, M_MOM] = NHCP('MM2', 'run', T_DISP, T_ROT);
```

where `'run'` for running the simulation and `T_DISP` and `T_ROT` are target displacement and rotation which are sent from UI-SIMCOR and double float, respectively. For `Sim1D` and `MM1` modes, there is one return variable, i.e., `M_FORCE` (measured force) and UI-SIMCOR assumes that the measured displacement is same with target displacement. For `MM2` mode, there are four return variables, i.e, `M_DISP` (measured displacement), `M_ROT` (measured rotation), `M_FORC`, `M_MOM` (measured moment). MiniMOST 1 in UIUC or SDSC has one DOF in translational direction (i.e, x-direction) and MiniMOST 2 in UIUC or SDSC has two DOFs in translational direction and rotation (i.e., x- and rz-direction).

For examples:

```
[M_FORC] = NHCP('Sim1D', 'run', 10);
[M_DISP, M_ROT, M_FORC, M_MOM] = NCHP('MM2', 'run', 10, 0.1);
```

close

Syntax:

```
NHCP(NHCPMode, 'close');
```

where `'close'` for disconnecting UI-SIMCOR from NCS and SimServer (or Mini MOST 1 or 2 computer). There is no return value during `'close'` action, instead there will be error messages in the NCS if there are some errors during `'close'` action.

For example:

```
NHCP('MM1', 'close');
```

7. Installation of UI-SIMCOR

All the files necessary to run UI-SIMCOR including NEES-SAM are posted on the NEESforge website (https://neesforge.nees.org/projects/simcor). After installation is complete, the user should be able to run the examples in Section 8. The distributed software is composed of following components.

- 01_SIMCOR : Simulation coordinator, a main control and integration module.
- 02_NEES-ABAQUS : Interface applications for ABAQUS
- 02_NEES-FL : Interface applications for FEDEAS Lab.
- 02_NEES-SAM : Interface applications for ZEUS-NL and OpenSees
- 03_Examples : Various examples including experimental test
- 04_API : API for specific experimental site

7.1 System Requirements

A MATLAB v6.5 or higher version with *Instrument Control Toolbox* is required UI-SIMCOR itself. Various structural analysis programs and some additional programs for specific communication protocols are also required. Installation instruction for each software will be explained.

7.2 Installation of UI-SIMCOR and Interface Application

The executable file for UI-SIMCOR v2.6 can be downloaded form the NEESforge website. Start from the NEESforge UI-SIMCOR page (https://neesforge.nees.org/projects/simcor) as shown in Figure 12.

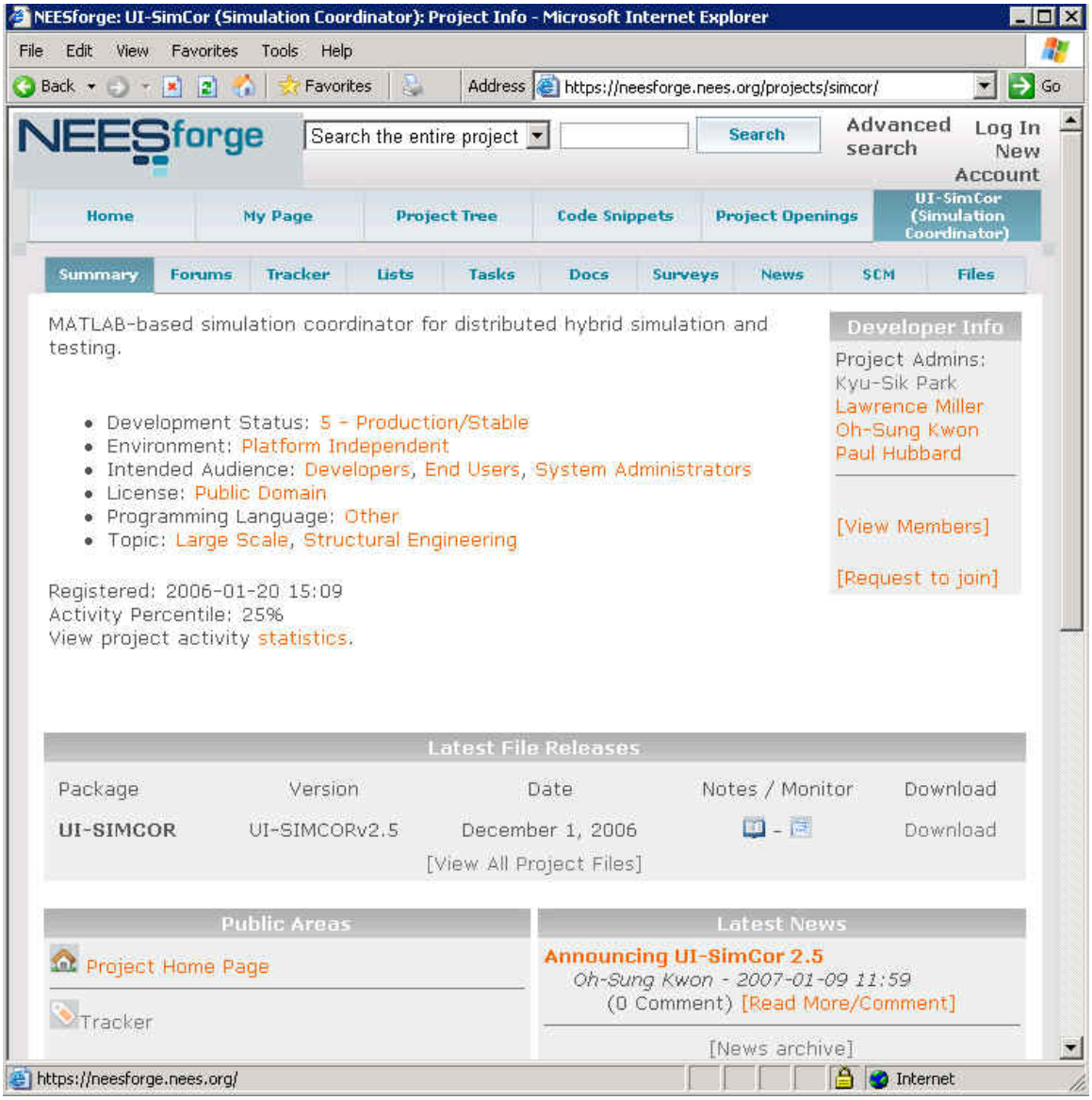


Figure 12 UI-SIMCOR project website on NEESforge

Click on any “Download” on the right side of the page. All links load the page shown in Figure 13.

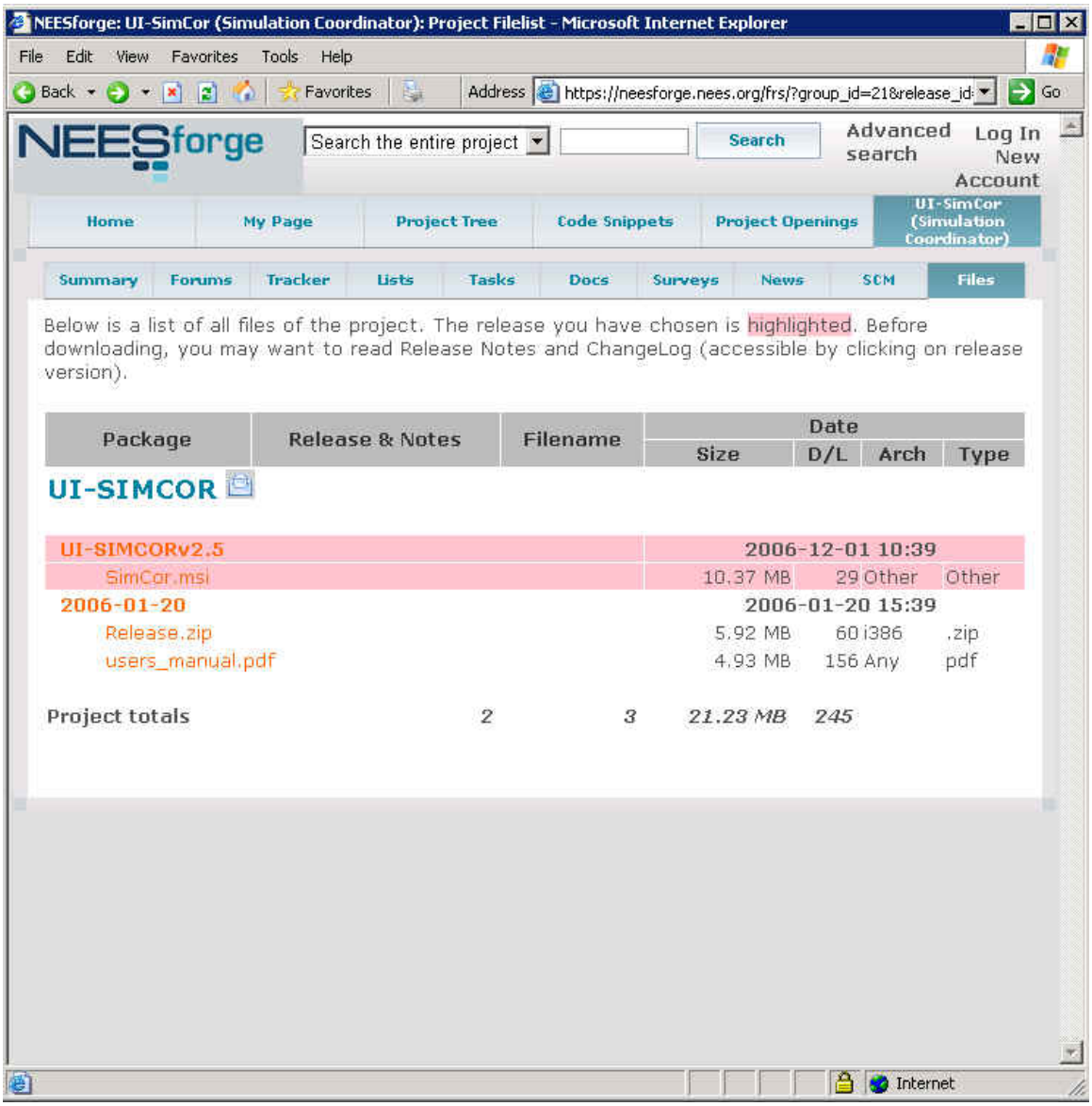


Figure 13 UI-SIMCOR download webpage on NEESit

Download UI-SIMCOR v2.6 by clicking on *SimCor.msi*. Currently, UI-SIMCOR v2.5 and v2.6 are available in the NEESforge website. By double clicking the downloaded file, you can install UI-SIMCOR, interface applications for structural analysis programs, and example files. **When you install software, DO NOT change the default folder location. The software should be installed in C:\SIMCOR.**

At the end of the installation process, you will see a message that some folders should be set in the search path of MATLAB. To do that, open MATLAB and click *File-Set Path*. Following folders should be in the search path of MATLAB.

Path for UI-SIMCOR

C:\SIMCOR\01_SIMCOR
C:\SIMCOR\01_SIMCOR\parmatlab

Path for FEDEAS Lab and NEES-FL

C:\SIMCOR\02_NEES-FL
C:\SIMCOR\02_NEES-FL\FedeasLab
C:\SIMCOR\02_NEES-FL\FedeasLab\Element_Lib
C:\SIMCOR\02_NEES-FL\FedeasLab\General
C:\SIMCOR\02_NEES-FL\FedeasLab\Geometry
C:\SIMCOR\02_NEES-FL\FedeasLab\Material_Lib
C:\SIMCOR\02_NEES-FL\FedeasLab\Output
C:\SIMCOR\02_NEES-FL\FedeasLab\Section_Lib
C:\SIMCOR\02_NEES-FL\FedeasLab\Solution_Lib
C:\SIMCOR\02_NEES-FL\FedeasLab\Utilities

Path for NEES-ABAQUS

C:\SIMCOR\02_NEES-ABAQUS

Path for API of UCB (If μNEES at UCB is used for experiment)

C:\SIMCOR\04_API\01_UCB

For simple procedure

1. Run a MATLAB
2. Click *File-Set Path-Add with Subfolders* in the menu bar and select C:\SIMCOR\01_SIMCOR and click the **OK** button
3. Repeat step 2 for C:\SIMCOR\02_NEES-FL, C:\SIMCOR\02_NEES-ABAQUS and C:\SIMCOR\04_API\01_UCB
4. Click **Save** button to save the paths and click **Close** button

7.3 Installation of Structural Analysis Software

The modified analysis softwares for the multi-site simulation are included in the distribution. Also FEDEAS Lab is included in the distribution. To edit and verify structural model for ZEUS-NL and OpenSees, each software should be installed separately.

The latest version of ZEUS-NL can be downloaded from the following link. By double clicking installation file, you can install the latest version of ZEUS-NL. If you encounter difficulties in modeling or running ZEUS-NL, contact Oh-Sung Kwon (okwon2@uiuc.edu) or Kyu-Sik Park (kspark@uiuc.edu).

http://mae.ce.uiuc.edu

OpenSees can be downloaded from the following link.

http://opensees.berkeley.edu

In the above link, there is detailed information about OpenSees. Tcl/Tk interpreter also should be installed to run OpenSees and OpenFresco. This is also needed for NEES-SAM when OpenSees is used as static analysis module.

OpenFresco including user's manual can be downloaded from the following link.

https://neesforge.nees.org/projects/openfresco

For the NHCP, the OpenSSL is required for communication between UI-SIMCOR and NCS. OpenSSL can be downloaded from the following link.

http://www.openssl.org/

Folder List after Installation

The folder list of installed UI-SIMCOR is shown in Figure 14.

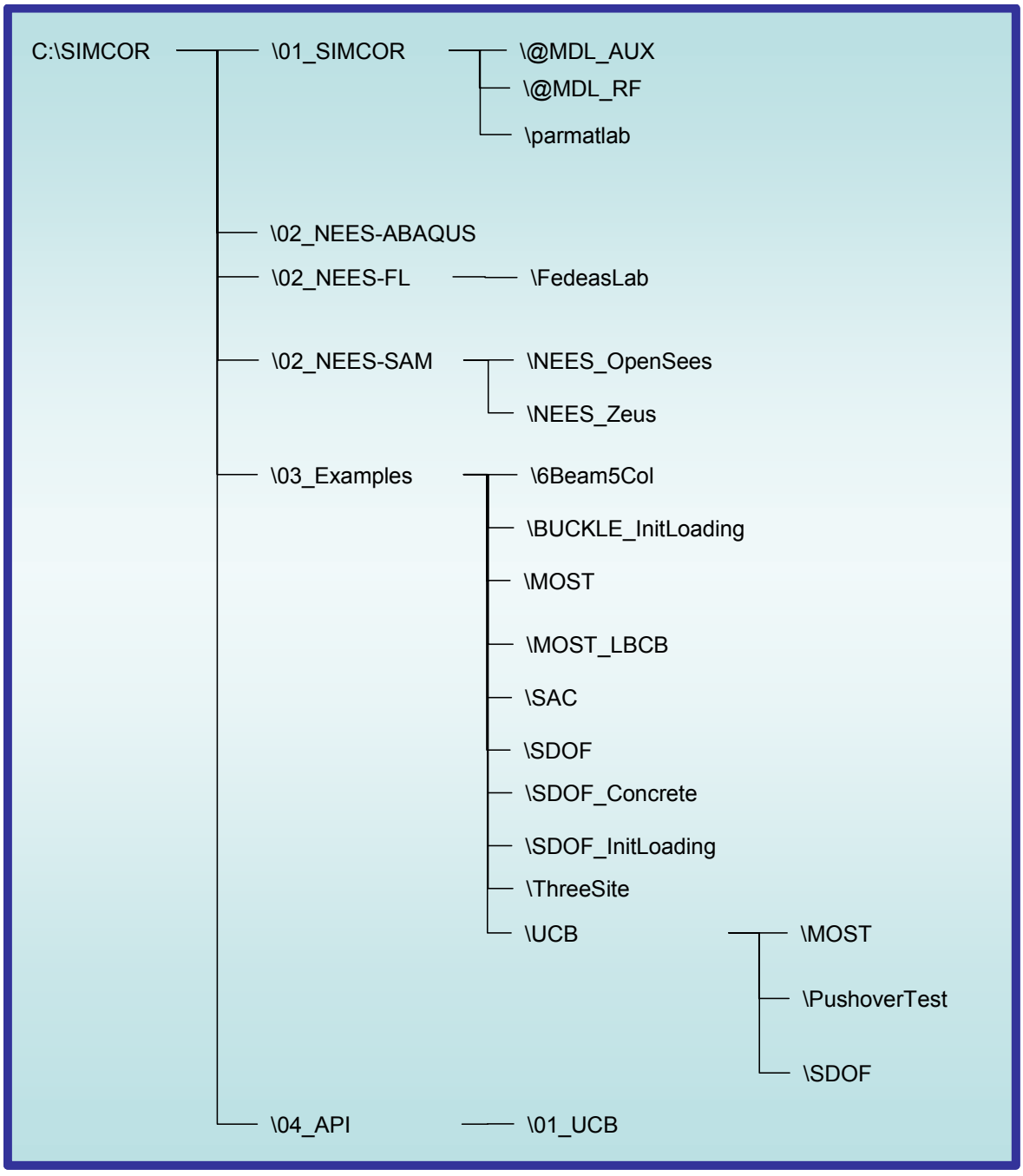


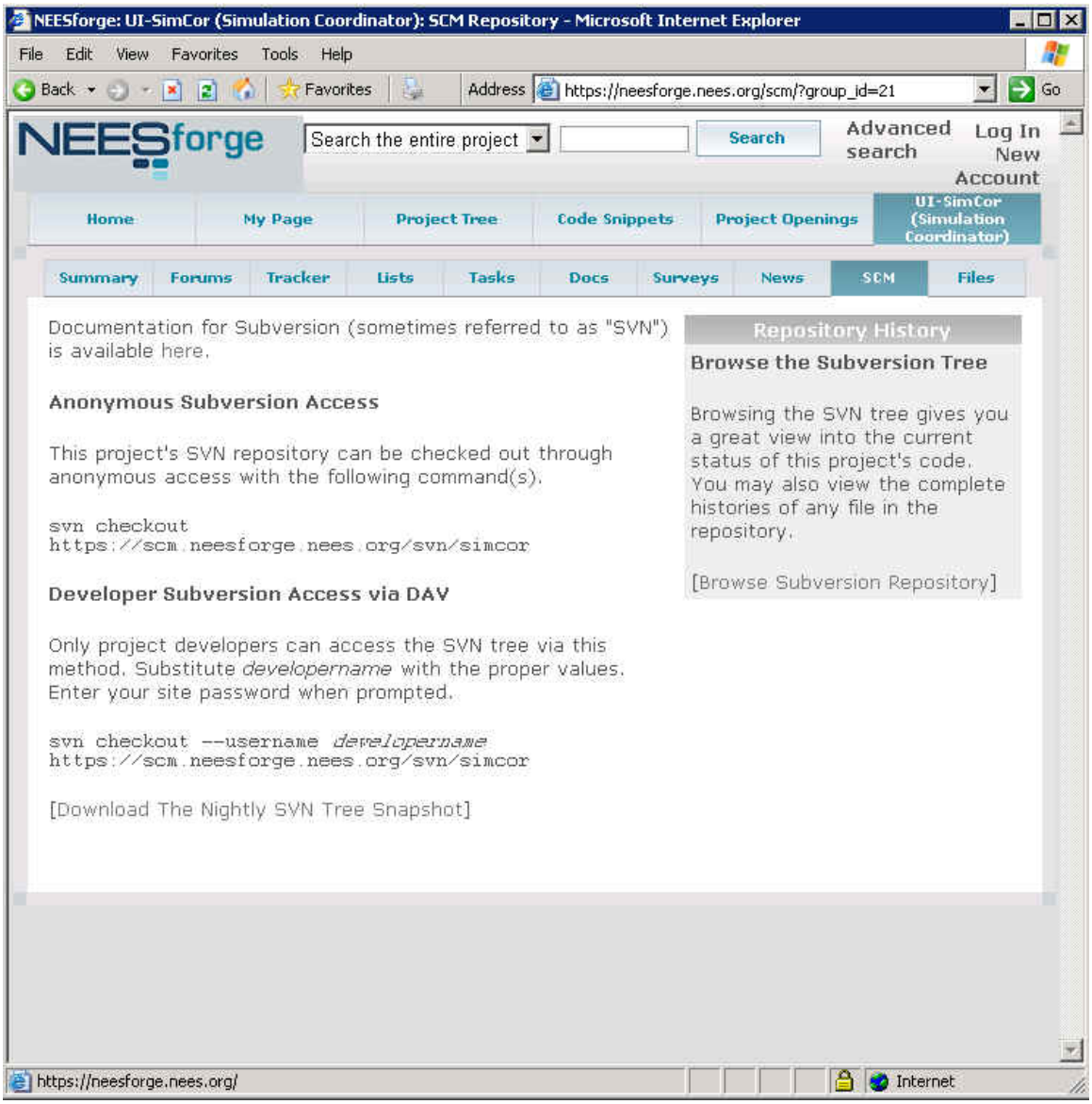
Figure 14 Folder list of UI-SIMCOR

7.4 Downloading and Updating UI-SIMCOR Source Code

The source code of UI-SIMCOR is already installed in the 01_SIMCOR folder of UI-SIMCOR installation directory. However, if you are interested in extending the software, the latest version of UI-SIMCOR source code is available for download using Subversion (SV). The Subversion is a version control system for software systems, a major component of Source Configuration Management (SCM) of SIMCOR Project in

NEESforge website. Subversion is commonly used in software development to record the history of sources files and documents.

At the top of the SIMCOR Project page of NEESforge, click on “SCM” tab and you can see the Figure 15.


NEESforge: UI-SimCor (Simulation Coordinator): SCM Repository - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Favorites Address https://neesforge.nees.org/scm/?group_id=21 Go
NEESforge
Search the entire project
Search
Advanced search
Log In
New Account
Home
My Page
Project Tree
Code Snippets
Project Openings
UI-SimCor (Simulation Coordinator)
Summary
Forums
Tracker
Lists
Tasks
Docs
Surveys
News
SCM
Files
Documentation for Subversion (sometimes referred to as "SVN") is available here.
Anonymous Subversion Access
This project's SVN repository can be checked out through anonymous access with the following command(s).
svn checkout
https://scm.neesforge.nees.org/svn/simcor
Developer Subversion Access via DAV
Only project developers can access the SVN tree via this method. Substitute developername with the proper values. Enter your site password when prompted.
svn checkout --username developername
https://scm.neesforge.nees.org/svn/simcor
[Download The Nightly SVN Tree Snapshot]
Repository History
Browse the Subversion Tree
Browsing the SVN tree gives you a great view into the current status of this project's code. You may also view the complete histories of any file in the repository.
[Browse Subversion Repository]
https://neesforge.nees.org/
Internet
Figure 15 UI-SIMCOR SCM webpage on NEESit

To browse the source code, click *Brows Subversion Repository* on the right side of the page. However, it is recommended to use Subversion software for downloading and updating the source code (Only authorized user can update the source code). The freely available Subversion software including documentation can be found in the following link.

http://tortoisesvn.net

The files in the “SCM” tab of NEESforge are the latest version of UI-SIMCOR source code, so it may have some bug or may not working. If user wants stable UI-SIMCOR source code, user needs install the latest version of UI-SIMCOR.

8. Numerical Examples

In this section, configuration and modeling guidelines for the UI-SIMCOR and NEES-SAM are introduced through various numerical examples.

8.1 Cantilever Column

A dynamic analysis of a cantilever column with a lumped mass is introduced here to demonstrate and verify each analysis module. The column is tested with elastic material without initial loading using three static analysis applications (FEDEAS Lab, ZEUS-NL, OpenSees, and ABAQUS). α -OS scheme with $\alpha = 0.05$, $\beta = 1/4 \cdot (1+\alpha)^2$ and $\gamma = 1/2 + \alpha$ is used for all the simulation. N-S component of the ground motion recorded at a site in El Centro, California, during the Imperial Valley earthquake of May 18, 1940 is used for all cantilever column examples.

8.1.1 Structural configuration

The column height is 3,500 mm with 10 N/(mm/sec^2) of mass at the top, Figure 16. Frame element is used to model the column. Only x-directional DOF is used for dynamic analysis. El Centro ground motion was applied along the x-direction at the base. Lumped mass is defined in simulation coordinator. Stiffness evaluation and static analysis is performed in static analysis module, FEDEAS Lab, ZEUS-NL, OpenSees, ABAQUS, OpenFresco, and NHCP Simulation Server.

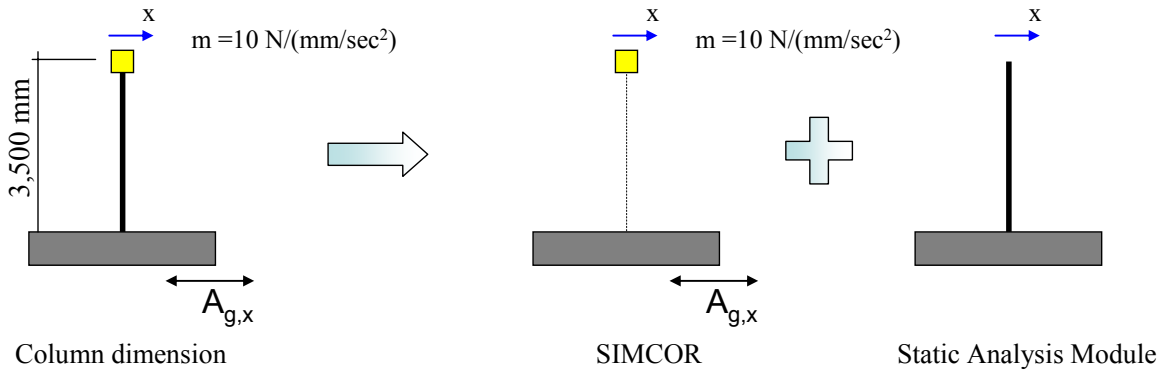


Figure 16 Column configuration

8.1.2 Simulation configuration file

Simulation configuration file contains all the information that is necessary for UI-SIMCOR for the multi-site simulation. Many parameters are trivial and self-explained.

Note that most of the parameters should be defined for all analysis and variable names should not be modified. The MATLAB script is case sensitive.

C:\SIMCOR\03_Examples\SDOF\00_Coordinator\SimConfig.m

```
function [Sys, MDL, AUX] = SimConfig
MDL = MDL_RF; AUX = MDL_AUX;        % Type definition. Do not delete this line.
% ========================================================================
% Configuration parameters for SDOF experiment
%
% Unit: mm, N, sec
%
% by Oh-Sung Kwon, okwon2@uiuc.edu
% modified by Kyu-Sik Park, kspark@uiuc.edu
% Univ. of Illinois at Urbana Champaign
%
% Last updated on 2007-01-26 11:05PM
% ========================================================================

% _____________________________________________________________________
%
% Common parameters
% _____________________________________________________________________

% Ground acceleration file name with extension. The file should contains two
% columns for time and acceleration. The unit of acceleration should be
% consistent with the mass, time, and force. (i.e. mass*acc = force)
Sys.GM_Input = 'elcentro.dat';

% Ground acceleration scale factor. This factor will be multiplied to
% acceleration before starting simulation.
Sys.GM_SC = 9810;

% Direction of ground acceleration. (x, y, or z)
Sys.GM_direction = 'x';

% Integration parameter related to the alpha-OS method.
% Alpha = (0 ~ 1/3). In most cases, SC.Alph = 0.05 worked.
Sys.Alph = 0.05;
Sys.Beta = 1/4*(1+Sys.Alph)^2;
Sys.Gamm = 1/2 + Sys.Alph;

% Evaluate Stiffness?
% Yes (1) to run stiffness evaluation test,
% No  (0) to read stiffness matrix from file. In this case, there should exist
%         stiffness matrices of individual module in the files MDL01_K.txt,
%         MDL02_K.txt, etc.
Sys.Eval_Stiffness = 1;

% Number of initial static loading steps. When there exist static constant
% loading,i.e. gravity forces, apply then in Zeus-NL or OpenSees as a
% incremental loading with 'n' steps. In this file, SimConfig.m, specify the
% number of static steps in the following variable.
Sys.Num_Static_Step = 0;

% Number of dynamic analysis steps
Sys.Num_Dynamic_Step = 500;

% Dynamic analysis time steps
Sys.dt = 0.01;
```

```
% Rayleigh damping, xi_1 and xi_2: Damping ratio, Tn_1, Tn_2: Target period
Sys.xi_1 = 0.00;
Sys.Tn_1 = 0.00;
Sys.xi_2 = 0.00;
Sys.Tn_2 = 0.00;

% Number of Stiffness test
% If stiffness is evaluated through experiment, the evaluation need to be done
% several times and the average of the results are used as the initial
% stiffness. This parameter is used when Sys.Eval_Stiffness = 1
Sys.Num_Test_Stiffness  = 1;

% Enable GUI for SimCor?
% Yes (1) enable the GUI for SimCor
% No  (0) disable the GUI for SimCor
%         Hybrid simulation will be run automatically.
%         Not recommended for the experiment.
Sys.EnableGUI       = 1;         % Use GUI for SimCor

% Number of restoring force modules.
Sys.Num_RF_Module     = 1;

% Number of auxilary modules.
Sys.Num_AUX_Module    = 0;

% Total number of effective nodes. Effective nodes are interface nodes between
% modules and nodes where lumped masses are defined.
Sys.Num_Node        = 1;

% Lumped mass assigned for each DOF for each node.
% Node number = x, y, z, rx, ry, rz directional mass
Sys.Node_Mass{1} = [10, 0, 0, 0, 0, 0];

% ____________________________________________________________________________
%
% Restoring force module configuration
% ____________________________________________________________________________

% Create objects of MDL_RF
MDL(1) = MDL_RF;

% Name of each module.
MDL(1).name = 'STATIC'; % Module ID of this module is 1

% URL of each module
% Format - IP address:port number
% ex) 'http://cee-nsp4.cee.uiuc.edu:11997'
%     for local machine - '127.0.0.1:11997'
MDL(1).URL  = '127.0.0.1:11997';

% Communication protocol for each module.
%       NTCP         : communicate through NEESPOP server
%       TCPIP        : binary communication using TCPIP
%       LabView1     : ASCII communication with LabView plugin format
%                      (Propose-Query-Execute-Query)
%       LabView2     : same as LabView1 but Propose-Query
%       OpenFresco1D : OpenFresco, only 1 DOF is implemented now.
%       NHCP         : NHCP, linear 1 DOF simulation mode, Mini MOST 1 and 2 at
%                      UIUC or SDSC
MDL(1).protocol = 'nhcp';

% Module 1: STATIC ------------------------------------------------------------
MDL(1).node    = [1];           % Control point node number
```

```
MDL(1).EFF_DOF = [1 0 0 0 0 0]; % Effective DOF for CP 1

% Dismplacement for preliminary test for each module
% Del_t: Translation, Del_r: Rotation in radian
MDL(1).DEL_t = 0.005;

MDL(1).DEL_r = 0.002;

% Enable GUI for each module?
% GUI for each module can only display the data.
% GUI for each module can not control the hybrid simulation.
% Yes (1) enable the GUI for each module
% No  (0) disable the GUI for each module
MDL(1).EnableGUI = 1;

% ____________________________________________________________________________
%
% Advanced modular parameters
% ____________________________________________________________________________
% These parameters need to be redefined for following situations.
%     (1) Different coordinate system between UI-SIMCOR and static module
%     (2) When scale factor needs to be applied either in experiment or
%         simulation
%     (3) To define force and displacement criteria (for tolerance and safety)
%     (4) To trigger camera modules or DAQ system
%     (5) When LBCB at UIUC is used for experiment
%     (6) When NHCP protocol is used
%
% URL of remote site and NHCP mode for NHCP
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).protocol), 'nhcp')
              MDL(i).remote_URL = '127.0.0.1:99999';
              MDL(i).NHCPMode = 'sim1d';
       end
end

% Stiffness for NHCP (Only valid if NHCPMode = 'Sim1D')
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).NHCPMode), 'sim1d')
              MDL(i).NHCPSimK = '6.2344023e+003';
       end
end

% Coordinate transformation. If it needs, the transformation matrix also
% needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).TransM = [];
end

% Scale factor for displacement, rotation, force, moment
% Experimental specimens are not always in full scale. Use this factors to
% apply scale factors.
% The displacement scale factors are multiplied before they are
% sent to module. Measured force and moments are divided with scale factors
% before used in the PSD algorithm.
for i=1:Sys.Num_RF_Module
       MDL(i).ScaleF = [1 1 1 1]; % Module i
end

% Relaxation check
% If this parameter is 1, UI_SimCor send commend to retrieve data and check
% relaxation just before the execution of proposed command. If it's 1, the
% checking criteria needs to be provided.
```

```
for i=1:Sys.Num_RF_Module
       MDL(i).CheckRelax  = 0;          % Module i
       % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement variation ratio (not increment)
  % MDL(i).MES_D_inc = [ a b c d e f
    %                    ...        ];
  % Force variaiton ratio (not increment)
  % MDL(i).MES_F_inc = [ a b c d e f
    %                    ...        ];
end

% Check displacement and force limit
% At every steps, check if the displacement or force are approaching to the
% limitation of the equipments stroke or force capacity.
for i=1:Sys.Num_RF_Module
  MDL(i).CheckLimit  = 0;   % Module i
  % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement increment limit(not ratio)
  % MDL(i).TGT_D_inc = [ a b c d e f
    %                    ...        ];
    % Displacement limit
  % MDL(i).CAP_D_tot = [ a b c d e f
    %                    ...        ];
    % Force limit
  % MDL(i).CAP_F_tot = [ a b c d e f
    %                    ...        ];
    % Displacement tolerance (ratio)
  % MDL(i).TOL_D_inc = [ a b c d e f
    %                    ...        ];
end

% Loading and Boundary Condition Box (LBCB) case. If it's 1, the
% coordinate transformation matrix needs to be provided.
% This can be also used for any other actuator which has diffrence number of
% DOF coordinate with those of UI-SIMCOR

for i=1:Sys.Num_RF_Module
       MDL(i).LBCB = 0;
end

for i=1:Sys.Num_RF_Module
       MDL(i).LBCB_TransM = [];
end

% ____________________________________________________________________________
%
% Auxiliary module configuration
% ____________________________________________________________________________

% AUX(1)                = MDL_AUX;
% AUX(1).URL            = '127.0.0.1:12000';
% AUX(1).protocol       = 'labview1';
% AUX(1).name           = 'Camera';     % Module ID of this mdoule is 1
% AUX(1).Command        = {'displacement' 'z' 3500};
```

Variable Description

Three classes are used in the simulation configuration file, i.e., Sys, MDL_RF, and MDL_AUX

Sys Class

A structure that includes all data about PSD simulation.

MDL_RF Class

A class for restoring force module. All remote experimental specimens will communicate with objects of this class.

MDL_AUX Class

A class for sending signals to auxiliary hardware such as DAQ and camera. This class also has similar member functions with MDL_RF.

The detailed descriptions of variables in each class are as follows.

Sys Class

Sys_GM_Input

This variable defines the ground acceleration file name with extension. The file should contain two columns for time and acceleration. The unit of acceleration should be consistent with the mass, time, and force (i. e., mass×acc = force).

Sys_GM_SC

This variable defines the ground acceleration scale factor. This factor will be multiplied to acceleration before starting simulation.

Sys_GM_direction

This variable defines the direction of ground acceleration (x, y, or z).

Sys_Alph, Sys_Beta, and Sys_Gamm

These variables define the integration parameters of α -OS scheme. The recommend range of α is $0 < \alpha < 1/3$ and $\alpha = 0.05$ works in the most cases. $\beta = 1/4 \cdot (1+\alpha)^2$ and $\gamma = 1/2 + \alpha$ are used during the simulation.

Sys.Eval_Stiffness

This variable defines the option of evaluation of stiffness. If YES (1), the stiffness evaluation test will be run. If NO (0), the stiffness matrix of structure is read from file. In this case, there should be exist stiffness matrices of individual module in the files MDL01_K.txt, MDL02_K.txt, etc.

Sys.Num_Static_Step

In UI-SIMCOR, PSD test is composed of four stages as explained in Section 2. During static loading stage, the gravity forces are applied incrementally and there are no inertial forces from ground acceleration. The gravity forces are applied incrementally since those forces can cause inelastic deformation such as cracking of concrete elements and yielding. During this stage, inelastic static analysis is performed using initial stiffness. Initial forces are applied in the static analysis module such as ZEUS-NL and OpenSees. For now, we cannot include initial loading in FEDEAS Lab. In this example, there is no initial loading. Thus the number of static step is zero. Next example includes initial loading. Further explanation will be given in next example.

Sys.Num_Dynamic_Step

This variable defines the number of dynamic analysis steps.

Sys.dt

This variable defines the dynamic analysis time steps.

Sys.xi_1, Sys.Tn_1, Sys.xi_2, and Sys.Tn_2

These variables define the Rayleigh damping parameters, i. e., Damping ratio (Sys.xi_1 and Sys.xi_2) and target period (Sys.Tn_1 and Sys.Tn_2).

Sys.Num_Test_Stiffness

This variable defines the number of stiffness test. If stiffness is evaluation through simulation module, one test is enough to evaluate the stiffness. However, if stiffness is evaluation through experiment, the evaluation need to be done several times and the average of the results are used as the initial stiffness. This parameter is used when Sys.Eval_Stiffness = 1.

Sys.EnableGUI

This variable defines the option of GUI for UI-SIMCOR control window. **If NO (0), the hybrid simulation will be run automatically, so it is not recommended for the experiment.**

Sys.Num_RF_Module

This variable defines the number of static analysis or experimental module. In this example, there is only one static analysis module which represents column elements. Thus it's 1.

Sys.Num_AUX_Module

This variable defines the number of auxiliary modules.

Sys.Num_Node

This variable defines total number of control points in the simulation coordinator. As it was discussed in Section 4, nodes where masses are located or where the DOFs are of interest are used in the time integration.

Sys.Node_Mass{*i*}

This variable defines nodal mass for each node. Lumped mass can be defined for each DOF for each control points. In this example, it is assumed that there is only x-directional mass.

MDL_RF Class

MDL(*i*).name

This variable define the name of each module.

MDL(*i*).URL

MDL(*i*).URL directs the address of server and port number for each module. For local machine, MDL(*i*).URL = '127.0.0.1:port number'.

MDL(*i*).protocol

This variable defines communication protocol for each module. Four protocols are available in the current version of UI-SIMCOR as follows

NTCP	: communicate through NEESPOP server
TCPIP	: binary communication using TCP/IP
LabView1	: ASCII communication with LabView plugin format (Propose-Query-Execute-Query)
LabView2	: same as LabView1 but Propose-Query.
OpenFresco1D	: OpenFresco, only 1 DOF is implemented now
NHCP	: NHCP, linear 1 DOF simulation mode, Mini MOST 1 and 2 at UIUC or SDSC

When FEDEAS Lab or ABAQUS is used as a static analysis module, only LabView2 protocol is available until now. When OpenFresco or NHCP Simulation Server is used as a static analysis module, only OpenFresco1D or NHCP protocol is available until now.

MDL(*i*).node

This cell array defines the control points that are connected to module *i*. Since there is only one control point in simulation coordinator and there is one module, it is naturally [1]. From latter examples, such as MOST example or SAC frame, you will get more explanation about node definition for each module.

MDL(*i*).EFF_DOF

In three-dimensional space, there are 6 DOFs for each node. If the structure behaves in plane and if other DOFs are not of interest, unnecessary DOFs can be condensed out. By defining effective DOFs, we can include DOFs of interest only and condense out unnecessary DOFs. In this example, inertial forces are applied in x-direction and x-direction is of our interest. Thus only x-directional DOFs are enabled and all other DOFs are disabled. The order of the DOFs are [x y z rx ry rz].

MDL(*i*).DEL_t, and MDL(*i*).DEL _r

These variables define the displacement level for the test for initial stiffness formulation. These variables should be defined for each module. The displacement for preliminary test may vary for each site and for translational and rotational displacement. If the module is computational and it behaves in the elastic range, the value is not important. **If the module is experimental and it can go to inelastic range, these variables should be chosen with care.**

MDL(*i*).EnableGUI

This variable defines the option of GUI for each module. It cannot control the hybrid simulation but only monitor the responses in real time (e. g., target displacement and measured displacement and force). This GUI is very similar to TH_MONITOR and DF_MONITOR of a static analysis module for ZEUS-NL and OpenSees.

Besides above variables, there are advanced modular parameters in MDL_RF class. Theses parameters need to be redefined for following situations.

- Different coordinate system between UI-SIMCOR and static module.
- When scale factor needs to be applied either in experiment or simulation.
- To define force and displacement criteria for tolerance and safety.
- To trigger camera modules or DAQ system.
- When LBCB at UIUC is used for experiment.
- When NHCP protocol is used.

MDL(*i*).remote_URL

MDL(*i*).remote_URL directs the address of remote site for each module when NHCP protocol is used. For local machine, MDL(*i*).remote_URL = '127.0.0.1:port number'.

MDL(*i*).NHCPMode

This variable defines the mode for NHCP protocol. This variable one of 'Sim1D' for simulation case, 'MM1', and 'MM2' for Mini MOST 1 and 2 at UIUC or SDSC, respectively. If NHCPMode is 'Sim1D', then MDL(i).NHCPSimK is required.

MDL(*i*).NHCPSimK

This variable defines the stiffness of Simulation Server for NHCP. Currently, only linear 1-DOF simulation case is available.

MDL(*i*).TransM

This variable defines the transformation matrix. If the coordinate system between UI-SIMCOR and static module is different, transformation matrix need to be given.

MDL(*i*).ScaleF

This variable defines the scale factor for displacement, rotation, force, and moment. Experimental specimens are not always in full scale. These factors can be used to apply scale factors. The displacement and rotation scale factors are multiplied before they are sent to module or experimental specimen. Measured forces and moments are divided with scale factors before used in the PSD algorithm. This scale factor can also be used to adjust the target displacement within the limit of experiment specimen.

MDL(*i*).CheckRelax

If the module is going to be experimented, the CheckRelax variable should be enabled. Then UI-SIMCOR checks relaxation of displacement and force before execution of proposed displacement in each time step. If MDL(*i*).CheckRelax = 1, following variables also need to be defined.

MDL(*i*).MES_D_inc: Displacement variation ratio (not increment)
MDL(*i*).MES_F_inc: Force variation ratio (not increment)

MDL(*i*).CheckLimit

If the module is going to be experimented, the CheckLimit variable should be enabled. Then UI-SIMCOR checks the target displacement, target displacement increment, measured force, and the difference between target and measured displacement. If MDL(*i*).CheckLimit = 1, following variables also need to be defined. All of following values are defined in the hybrid simulation framework not in the remote site.

MDL(*i*).TGT_D_inc

Target displacement increment constraint. Target displacement increment is defined as below

```
Disp_incre = abs(TGTD{i}.Disp-TGTD_0{i}.Disp);
```

If the target displacement increment is larger than MDL(*i*).TGT_D_incvalues, UI-SIMCOR generates an error message and cancel the proposed step.

MDL(*i*).CAP_D_tot

Absolute displacement constraint. Theses values should be given for each control points and for each DOFs. If the DOFs are not used in the UI-SIMCOR, you can input any number except zero.

If any current displacement at each DOF is larger than the displacement defined in MDL(*i*).CAP_D_tot, UI-SIMCOR generates error message and cancel the proposed step.

MDL(*i*).CAP_F_tot

Absolute force constraint. This variable does same role with MDL(*i*).CAP_D_tot except that it check for force.

MDL(*i*).TOL_D_inc

Displacement tolerance criteria. In the experimental module, the hydraulic system cannot exactly impose the proposed target

displacement. There can be difference between proposed and actually imposed displacement. If this displacement difference ratio is larger than MDL(*i*).TOL_D_inc, UI-SIMCOR cancels the current step.

MDL(*i*).LBCB
: This variable defines the option of Loading and Boundary Condition Box (LBCB). UI-SIMCOR only calculates the target displacements of effective DOFs. However, experimental equipment can have difference number of actuators with effective DOFs. The LBCB at UIUC has 6 actuators, so 6 displacements should be sent to LBCB for experiment. If YES (1), the target displacements of all DOFs will be assigned as zero except effective DOFs in UI-SIMCOR. If MDL(*i*).LBCB = 1, MDL(*i*).LBCB_TransM also needs to be defined.

MDL(*i*).LBCB_TransM
: This variable defines the transformation matrix for LBCB. The coordinate system of LBCB is dependent on the location of plate.

MDL_AUX Class

AUX(*i*).URL, AUX(*i*).protocol, and AUX(*i*).name
: Same as MDL(*i*).URL, MDL(*i*).protocol, and MDL(*i*).name for each auxiliary module.

AUX(*i*).command
: This variable define the command for each auxiliary module.

8.1.3 Static analysis module configuration

In section 8.1.2, a configuration file for UI-SIMCOR was explained. In this section, configuration file for static analysis module, such as FEDEAS Lab, ZEUS-NL, OpenSees, and ABAQUS will be explained.

FEDEAS Lab Module

Detailed description about modeling for FEDEAS Lab is not given in this document. However, the following should be kept in mind when a FEDEAS Lab model will be used as a part of simulation.

- clear, or CleanStart command should not be used. Those commands wipe out all the configuration information during simulation.

- Do not include 'Model = Create_Model()' command. The command will be called in NEES_FL_LabView2.m. The model file should have information about nodes, elements, material and section properties, boundary conditions only. All other parameters related to analysis will be given from NEES_FL_LabView2.m automatically. The easiest way to start working on FEDEAS model for distributed simulation is starting from example file, such as SDOF.m, rather than starting from scratch.

You can find very well documented manual from following link.

http://www.ce.berkeley.edu/~filippou/FEDEASLab/FEDEASLab.htm

The following is a description of configuration file for FEDEAS Lab Module.

C:\SIMCOR\03_Examples\SDOF\01_FEDEAS\FedeasCFG.m

```
%=========================================================================
% Configuration parameters for FedeasMDL
% SDOF cantilever model
%
% Unit: mm, N, sec
%
% Generated by Oh-Sung Kwon, okwon2@uiuc.edu
% Modified by Kyu-Sik Park, kspark@uiuc.edu
% Univ. of Illinois at Urbana Champaign
% Last updated on 2006-11-29 10:03PM
%=========================================================================

% Connection port to controller
MDL.Port = 11997;

% Module node number. Order of node number should be identical to the
% corresponding node number in the simulation coordinator
MDL.MDL_Node = [2];

% Effective DOFs. '1' specifiy the DOFs controlled by displacement.
MDL.EFF_DOF{1} = [1 0 0 0 0 0];

% Fedeas Lap input file name without extension
MDL.FEDEAS_MDL = 'SDOF';

% Dimension of the model. 2 or 3. 3 Dimensional model are not tested yet
% using FEDEAS Lab
MDL.MDL_Dim = 2;
```

Variable Description

MDL.Port

This variable defines the port number for LabView2 protocol.

MDL.MDL_Node

This variable defines the node number in the module. In SimConfig.m, it was defined that this module has node number '1'. That node number was for simulation coordinator. MDL_Node number is node number in FEDEAS Lab which corresponds to the node number in simulation coordinator. See following figure.

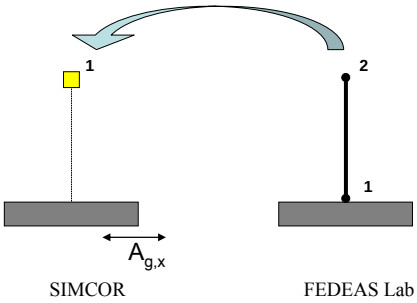


Figure 17 Module node number definition for FEDEAS Lab

MDL.EFF_DOF{*i*}

This variable defines the effective DOF for the i^{th} node. This should be identical to that defined in SimConfig.m. In SimConfig.m it is given that only x-directional translation will be participate in the simulation. In this configuration file, MDL.EFF_DOF{1} should also be defined with same information.

MDL.FEDEAS_MDL

This variable defines the FEDEAS Lab model file name without extension. In the model file, nodes, elements, boundary conditions, section properties, material properties, etc. are defined.

MDL.MDL_Dim

This variable defines the dimension of the model, i.e., 2 or 3. 3 dimensional model are not tested yet using FEDEAS Lab.

ZEUS-NL Module

ZEUS-NL Model and OpenSees Model can participate in the PSD test by using NEES-SAM as an interface module. Original version of ZEUS-NL cannot take displacements from the other software or user. Thus the Solver of the ZEUS-NL was modified to take displacement input for each time step from console and make a force output file in each time step. Following is key points for modeling of ZEUS-NL.

- Analysis type should be Static-Time History Analysis
- Time history curve should be defined. The value of the time history curve can be any value for the modified solver. Uniform curve is used in the example.

The time history curve should be defined for a large enough duration for whole simulation.

- In the Applied-Loading tab, static time-history load should be defined for each control points and for each DOF. Any load factor can be used. In this example, load factor of 1 is used. The order of the static time history loading should be;
    1. The control points should follow the order in the configuration file.
    2. The DOFs should be defined in the order of x, y, z, rx, ry, and rz.
- In this example, only one control point and one DOF is defined. Thus order doesn't matter. More examples will be given in the later section.

The following gives explanation about the configuration file for ZEUS-NL Module.

C:\SIMCOR\03_Examples\SDOF\02_ZEUS\Module.cfg

```
#=============================================================================
# Configuratino parameters for Zeus-NL
# Left column of MOST experiment
#
# Unit: mm, N, sec
#
# Generated by Oh-Sung Kwon, okwon2@uiuc.edu
# Univ. of Illinois at Urbana Champaign
# Last updated on 2006-08-06 9:35PM
#=============================================================================

# Connection port to controller
Port = 11997

# Module application, 1 for Zeus-NL, 2 for OpenSees
MDL_Type = 1

# Effective node numbers in Simulaiton coordinator.
#  The order of node number should be idntical to that specified in the
simulaiton
# coordinator configuration file.
SC_Node  = [1]

# Corresponding effective node numbers in this model.
MDL_Node = [n2]

# Effective DOFs in control point.
EFF_DOF: Use one line per each control point
1 0 0 0 0 0

# Zeus model file name without extension
MODEL = 'SDOF'

# Model dimension
MDL_Dim = 2

# Time history monitoring point, Node number, direction (x, y, z, rx, ry, rz),
D for disp or F for force
# This should be defined after SC_Node and MDL_Node
TH_MONITOR = 2, x, D

# Disp-Force monitoring point
DF_MONITOR = 2, x
```

Variable Description

Port

This variable defines the port number that the NEES-SAM will open and waiting for connection.

MDL_Type

This variable defines the module application, 1 for ZEUS-NL and 2 for OpenSees.

SC_Node

This variable defines the effective node number in simulation coordinator. The order of node number should be identical to that specified in the simulation coordinator configuration file.

MDL_Node

This variable has same role with MDL.MDL_Node in the configuration file for FEDEAS Lab. It identifies which nodes are related to the node number in simulation coordinator. See following figure.

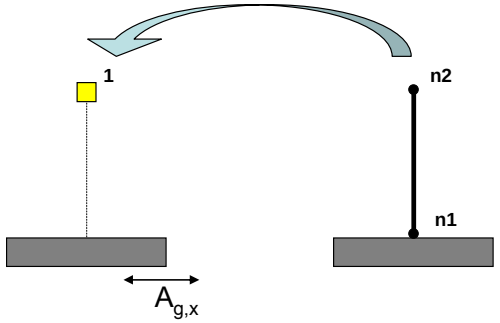


Figure 18 Module node number definition for ZEUS-NL

EFF_DOF{*i*}

This variable has a same function with MDL.EFF_DOF{*i*} in the configuration for FEDEAS Lab.

MODEL

ZEUS-NL model file name without extension.

MDL_Dim

This variable has a same function with MDL.MDL_Dim in the configuration for FEDEAS Lab.

TH_MONITOR

Time history monitoring. By defining this variable, real-time monitoring window pops up from the beginning of the test. Every DOFs displacement and force can be monitored in real time. Instead of this monitor, there are also monitoring windows of GUI in UI-SIMCOR (see MDL(*i*).EnableGUI in the simulation configuration file).

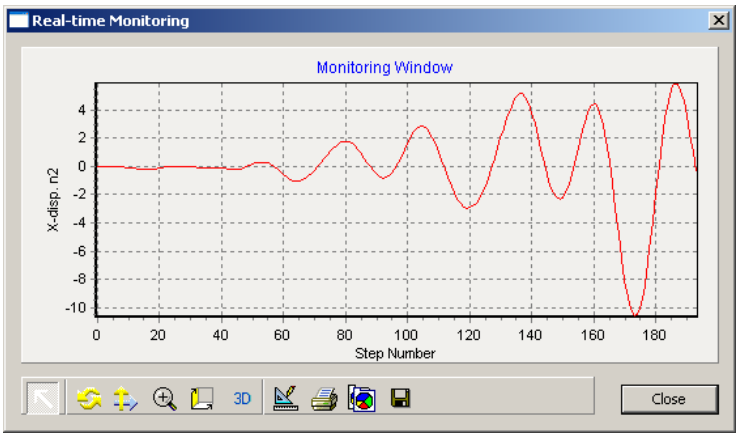


Figure 19 Time history monitoring window

DF_MONITOR

Deformation – Force monitor. By defining this variable, real-time monitoring window pops up to show displacement-force relation ship. The chart is updated at each time step. This monitor is also available in UI-SIMCOR.

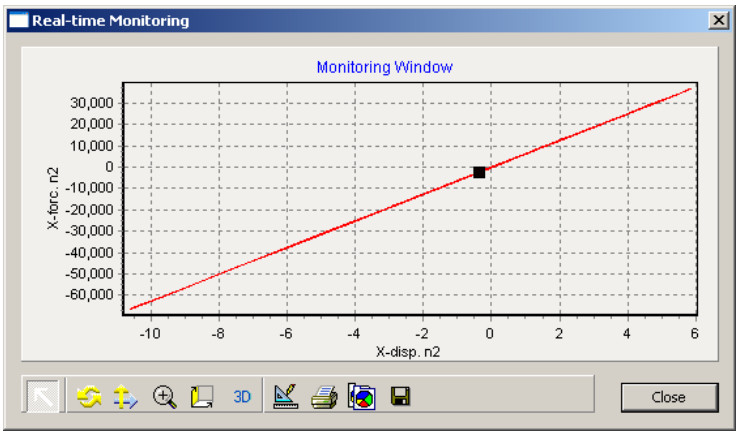


Figure 20 Displacement-Force monitoring window

OpenSees Module

OpenSees Model can participate in the PSD test by using NEES-SAM as an interface module. Original version of OpenSees was modified to make a displacement output file for each time step. The file is read by NEES-SAM and convert displacement to reaction forces. Detailed explanation about the modeling of OpenSees is not given in this document. You can find very well documented manual from following link.

http://opensees.berkeley.edu/

To use OpenSees as a static analysis module in PSD test simulation using UI-SIMCOR and NEES-SAM, following points should be accounted for.

- In modeling file, only node, element, material, section properties, and boundary conditions are given. Other parameters, as shown below, should be given in a separate file named as 'StaticAnalysisEnv.tcl'. Please do not attempt to modify the parameters unless you understand thoroughly.

```
system BandGeneral
constraints Penalty 1E20 1E20
numberer Plain
test NormDispIncr 1.0e-5 10 0
algorithm ModifiedNewton
integrator LoadControl 1
analysis Static
```

- Do not use recorder command. It is used by NEES-SAM to make a displacement output for control points and attached nodes.

The following gives explanation about the configuration file for OpenSees Module.

C:\SIMCOR\03_Examples\SDOF\03_OpenSees\Module.cfg

```
#=========================================================================
# Configuration parameters for Open-Sees
# SDOF cantilever model
#
# Unit: mm, N, sec
#
# Generated by Oh-Sung Kwon, okwon2@uiuc.edu
# Univ. of Illinois at Urbana Champaign
# Last updated on 2006-09-19 10:52PM
#=========================================================================

# Connection port
Port = 11997

# Module application, 1 for Zeus-NL, 2 for OpenSees
MDL_Type = 2

# Effective node numbers in Simulaiton coordinator.
# The order of node number should be idntical to that specified in the
# simulaiton coordinator configuration file.
SC_Node  = [1]

# Corresponding effective node numbers in this model.
MDL_Node = [2]

# Effective DOFs in control point.
EFF_DOF: Use one line per each control point
1 0 0 0 0 0

# model file name without extension
MODEL_FILE = 'SDOF'

# Model dimension
MDL_Dim = 3

# Time history monitoring point, Node number, direction (x, y, z, rx, ry, rz),
```

```
# D for disp or F for force
# This should be defined after SC_Node and MDL_Node
TH_MONITOR = 2, x, D

# Disp-Force monitoring point
DF_MONITOR = 2, x
```

Variable Description

All parameters are same for ZEUS-NL Model.

ABAQUS Module

Detailed description about modeling for ABAQUS is not given in this document. However, you can find very well documented information from following link.

http://www.abaqus.com/

The current static analysis module for ABAQUS is tested under ABAQUS v6.4.3 and v6.5.1. If different version of ABQUAS uses different output format, PostResult.m in 02_NEES-ABAQUS should be modified following new output format. However, this will be really minor modification. Furthermore, there is one restraint in ABAQUS input file. It is option for imposing target displacement in the model. The restraints is that the order of the DOFs in the command (*boundary) should be the same as that of MDL(*i*).EFF_DOF in the ABAQUS configuration file. This will be further explained in Section 7.5.

The ABAQUS Module is developed based on the FEDEAS Lab Module, so a description of configuration file for ABAQUS Module is very similar to that of FEDEAS Lab.

C:\SIMCOR\03_Examples\SDOF\04_Abaqus\AbaqusCFG.m

```
%=========================================================================
% Configuration parameters for AbaqusMDL
% SDOF cantilever model
%
% Unit: mm, N, sec
%
% Modified by GunJin Yun, gunjin73@hotmail.com
% Generated by Oh-Sung Kwon, okwon2@uiuc.edu
% Modified by Kyu-Sik Park, kspark@uiuc.edu
% Univ. of Illinois at Urbana Champaign
% Last updated on 2006-11-29 10:09PM
%=========================================================================

% Connection port to controller
MDL.Port = 11997;

% Module node number. Order of node number should be identical to the
% corresponding node number in the simulation coordinator
MDL.MDL_Node = [2];
```

```
% Effective DOFs. '1' specifiy the DOFs controlled by displacement.
MDL.EFF_DOF{1} = [1 0 0 0 0 0];

% Abaqus input file with extension
MDL.ABAQUS_MDL = 'SDOF.inp';

% Dimension of the model. 2 or 3. 3 Dimensional model are not tested yet
% using Abaqus
MDL.MDL_Dim = 2;

% The number of static analysis steps for initial loading -- Added by GunJin
Yun
MDL.Num_Static_Step=0;

% Number of Stiffness test                        -- Added by GunJin Yun
% If stiffness is evaluated through experiment, the evaluation need to be done
% several times and the average of the results are used as the initial
% stiffness. This parameter is used when MDL.Eval_Stiffness = 1
MDL.Num_Test_Stiffness=1;
```

Variable Description

All variables except following two parameters are exactly same with FEDEASE Lab except two variables.

MDL.Num_Dynamic_Step

This variable defines the number of dynamic analysis steps. It should be same with Sys.Num_Dynamic_Step variable in simulation configuration file.

MDL.Num_Test_Stiffness

This variable defines the number of stiffness test. It should be same with Sys.Eval_Stiffness variable in simulation configuration file.

8.1.4 Running simulation

The PSD test for this example requires two processes, one for UI-SIMCOR and the other one for static analysis module. Both processes can be run in a single computer or in multiple computers. The procedure for running this example is given as below.

1. Prepare configuration file. The network setting (e.g., port number in each static analysis module configuration file should be identical with the simulation coordinator file.) should be carefully set.
2. Prepare static module
    a. If FEDEA Lab or ABAQUS is used,
        i. Start a MATLAB
        ii. For FEDEAS Lab: Change current directory to the folder where FedeasCFG.m and the model file, SDOF.m, exist.
        For ABAQUS: Change current directory to the folder where AbaqusCFG.m and the model file, SDOF.inp, exist.

iii. For FEDEAS Lab: Run FEDEAS Lab by inputting following command.
NEES_FL_LabView2 [enter] for LabView2 protocol (See Figure 21).
For ABAQUS: Run ABAQUS by inputting following command.
NEES_Abaqus_LabView2 [enter] for LabView2 protocol (See Figure 22).

b. If ZEUS-NL or OpenSees are used with NEES-SAM,
   i. Start NEES-SAM by double clicking NEESSAM_TCPIP.exe (tcpip protocol) or NEESSAM_LabView1.exe (LabVIEW1 protocol) or NEESSAM_LabView2.exe (LabVIEW2 protocol).
   ii. Select the configuration file from the folder where configuration file and model file exist.
   iii. Check the open port and status (See Figure 23).

c. If OpenFresco is used,
   i. Start WINDOW DOS command window and change current directory to the folder where the model file, SDOF.tcl, exists.
   ii. Run OpenFresco by inputting **OpenFresco [enter]**.
   iii. Load model file by inputting **source SDOF.tcl [enter]** (See Figure 24).

d. If NHCP Simulation Server is used,
   i. Start WINDOW DOS command window and change current directory to the folder where the ncs.exe exists.
   ii. Run NCS by inputting **ncs portnumber [enter]** where portnumber is defined in the SimConfig.m file (MDL(i).URL, see Figure 25).
   iii. Start another WINDOW DOS command window and change current directory to the folder where the simserver.exe exists.
   iv. Run SimServer by inputting **simserver portnumber [enter]** where portnumber is defined in the SimConfig.m file (MDL(i).remote_URL, see Figure 26).

3. Run one MATLAB for UI-SIMCOR (Two MATLAB are required when FEDEAS Lab or ABAQUS is used as static module, i.e., one is for communication and the other is for UI-SIMCOR). Change current directory to the folder where SimConfig.m and ground motion file is located. Run UI-SIMCOR by inputting following command.
   UI_SIMCOR [enter] (See Figure 27)
4. There are two options in the UI-SIMCOR control GUI, i.e., 'Step by step control' and 'All steps by one click'.
   a. 'Step by step' run the 'Establish Connection', 'Stiffness Evaluation', 'Apply Static Loading', 'Start PSD Test', and 'Disconnect Modules' in order by clicking the each button.
   b. 'All steps by one click' run the all steps automatically by clicking the start button.

5. There is a simulation monitor for each module. This monitor shows the current status of hybrid simulation. 'HSF' option shows the results after scaling whereas 'Remote site' shows the results before scaling.

Please note that the above procedure should be followed whenever new analysis starts.

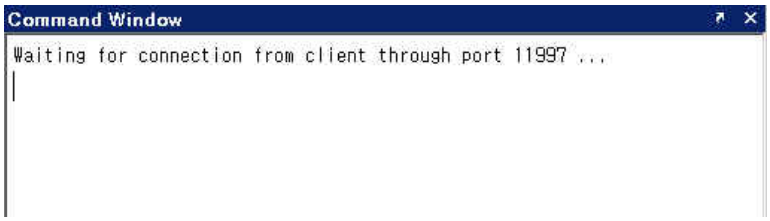


Figure 21 MATLAB command window after NEES_FL_LabView2.m command

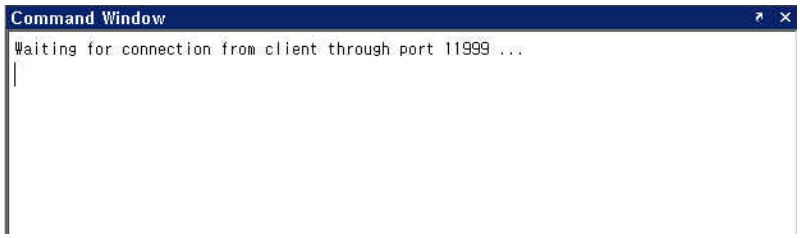


Figure 22 MATLAB command window after NEES_Abaqus_LabView2.m command

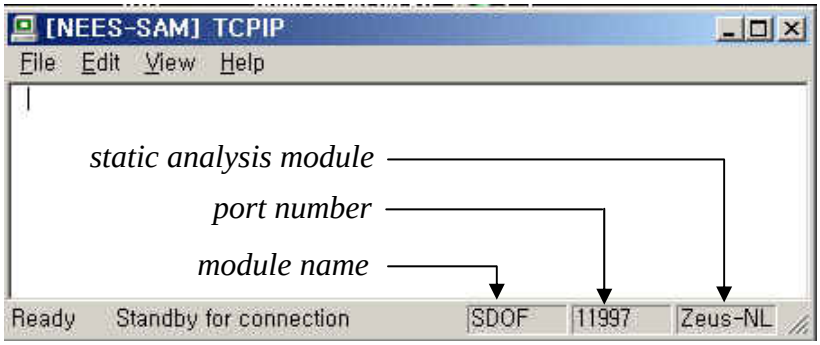


Figure 23 TCP/IP protocol window

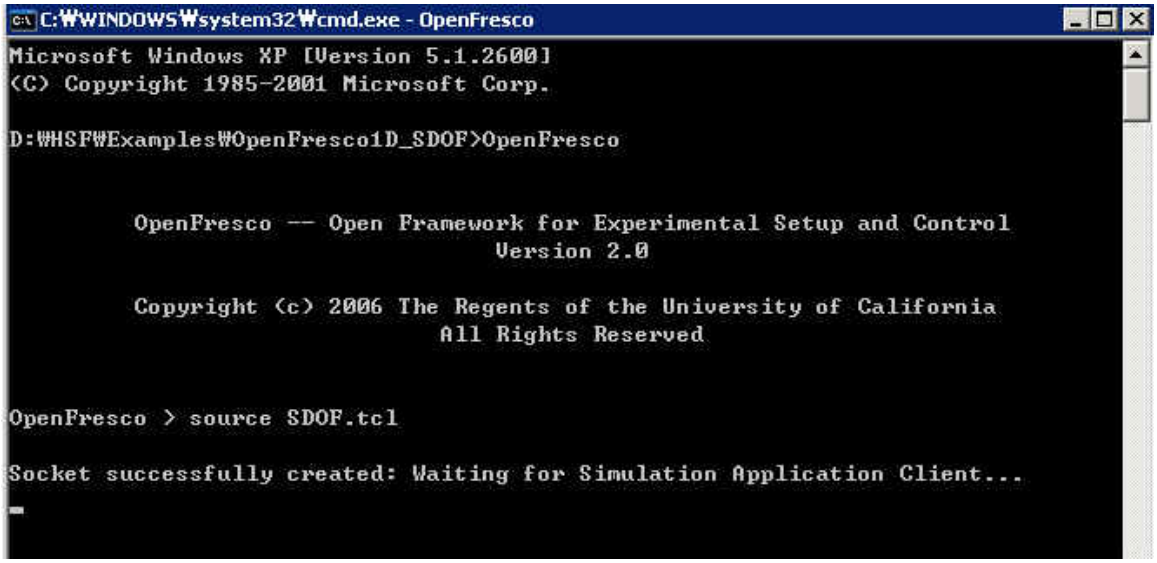

C:₩WINDOWS₩system32₩cmd.exe - OpenFresco
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.
D:₩HSF₩Examples₩OpenFresco1D_SDOF>OpenFresco
OpenFresco -- Open Framework for Experimental Setup and Control
Version 2.0
Copyright (c) 2006 The Regents of the University of California
All Rights Reserved
OpenFresco > source SDOF.tcl
Socket successfully created: Waiting for Simulation Application Client...

Figure 24 WINDOW DOS command window after running OpenFresco

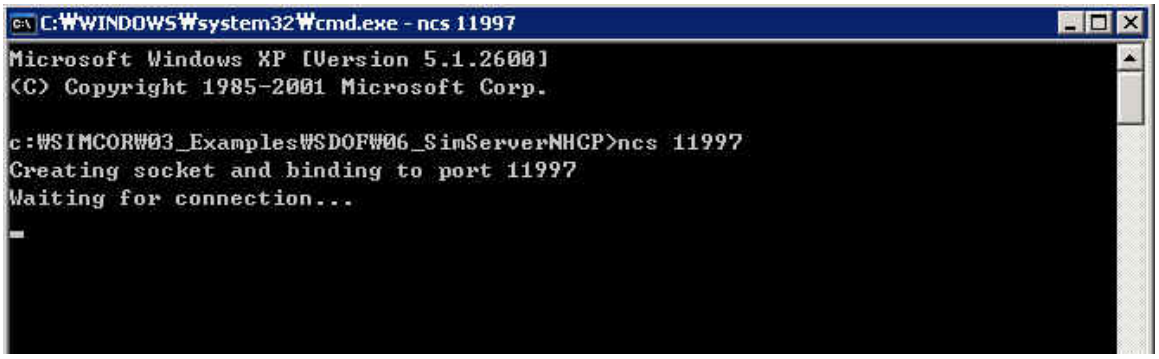

C:₩WINDOWS₩system32₩cmd.exe - ncs 11997
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.
c:₩SIMCOR₩03_Examples₩SDOF₩06_SimServerNHCP>ncs 11997
Creating socket and binding to port 11997
Waiting for connection...

Figure 25 WINDOW DOS command window after running NCS for NHCP

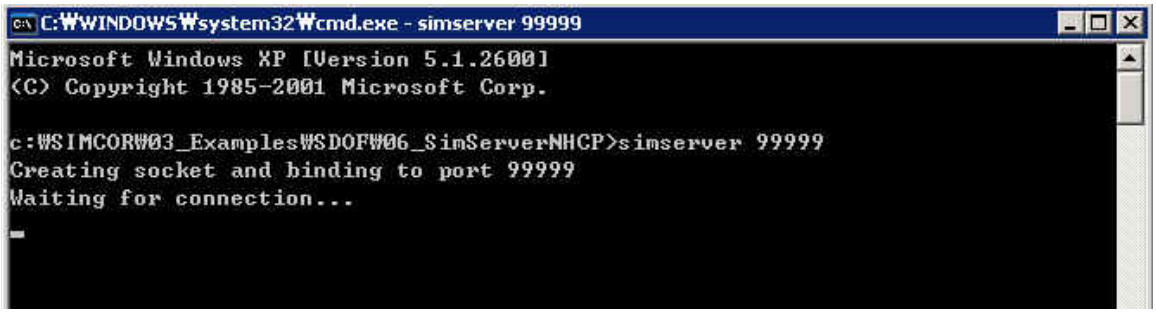

C:₩WINDOWS₩system32₩cmd.exe - simserver 99999
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.
c:₩SIMCOR₩03_Examples₩SDOF₩06_SimServerNHCP>simserver 99999
Creating socket and binding to port 99999
Waiting for connection...

Figure 26 WINDOW DOS command window after running SimServer for NHCP

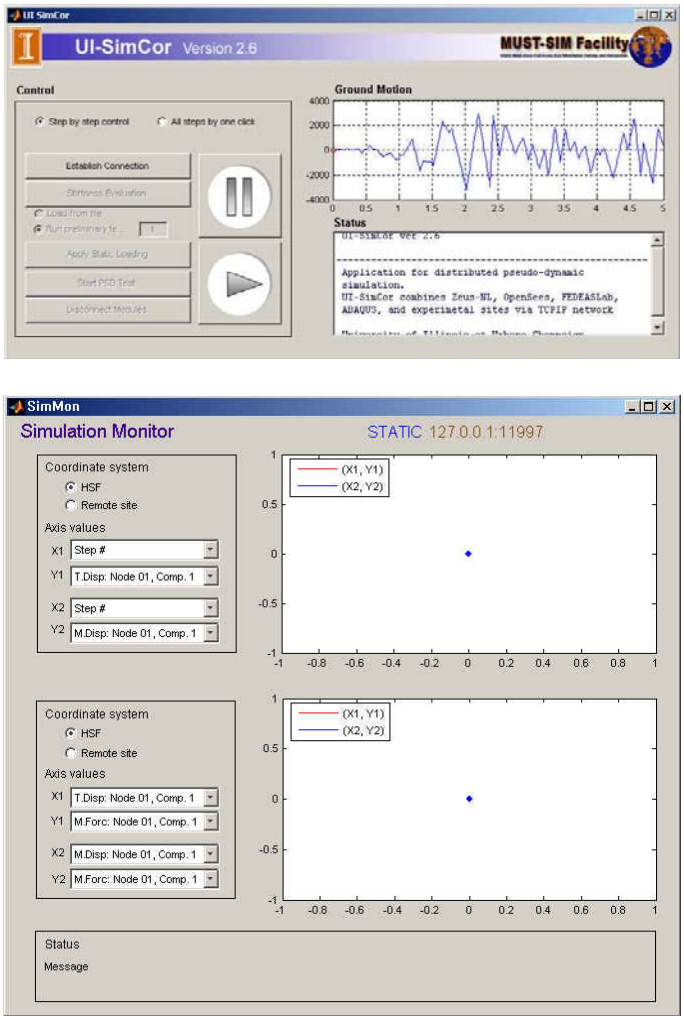


Figure 27 UI-SIMCOR control window and simulation monitor window

8.1.5 Result and verification

Following files will be generated after analysis.

C:\SIMCOR\03_Examples\SDOF\00_Coordinator

Global_K.txt	Stiffness matrix from initial stiffness evaluation
MDL01_K.txt	Stiffness matrix of module 1. In this example, only one module exists.
MDL01_recv.txt	This file contains received data from module 1. The displacements and forces are after coordinate transformation and scaling, if necessary.
NodeDisp.txt	Nodal displacements. Node numbers corresponds to the node number for UI-SIMCOR.
NetwkLog.txt	Communication log file

C:\SIMCOR\03_Examples\SDOF\01_Fedeas

NetwkLog.txt Communication log file

C:\SIMCOR\03_Examples\SDOF\02_ZEUS
- Cur_Disp.txt Current displacement after each step analysis
- Cur_Forc.txt Current force after each step analysis
- NetLog.txt Communication log file

C:\SIMCOR\03_Examples\SDOF\03_OpenSees
Same as 02_ZEUS

C:\SIMCOR\03_Examples\SDOF\04_Abaqus
Same as 01_Fedeas

In the folder 'C:\SIMCOR\03_Examples\SDOF\WholeModel', there is a whole model for each static analysis application.

Figures 28 and 29 show the input earthquake and the PSD test results for each static analysis module.

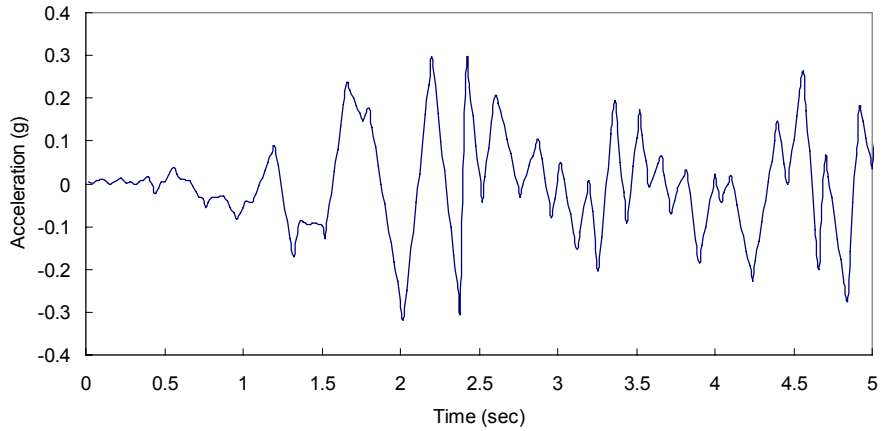


Figure 28 El Centro earthquake

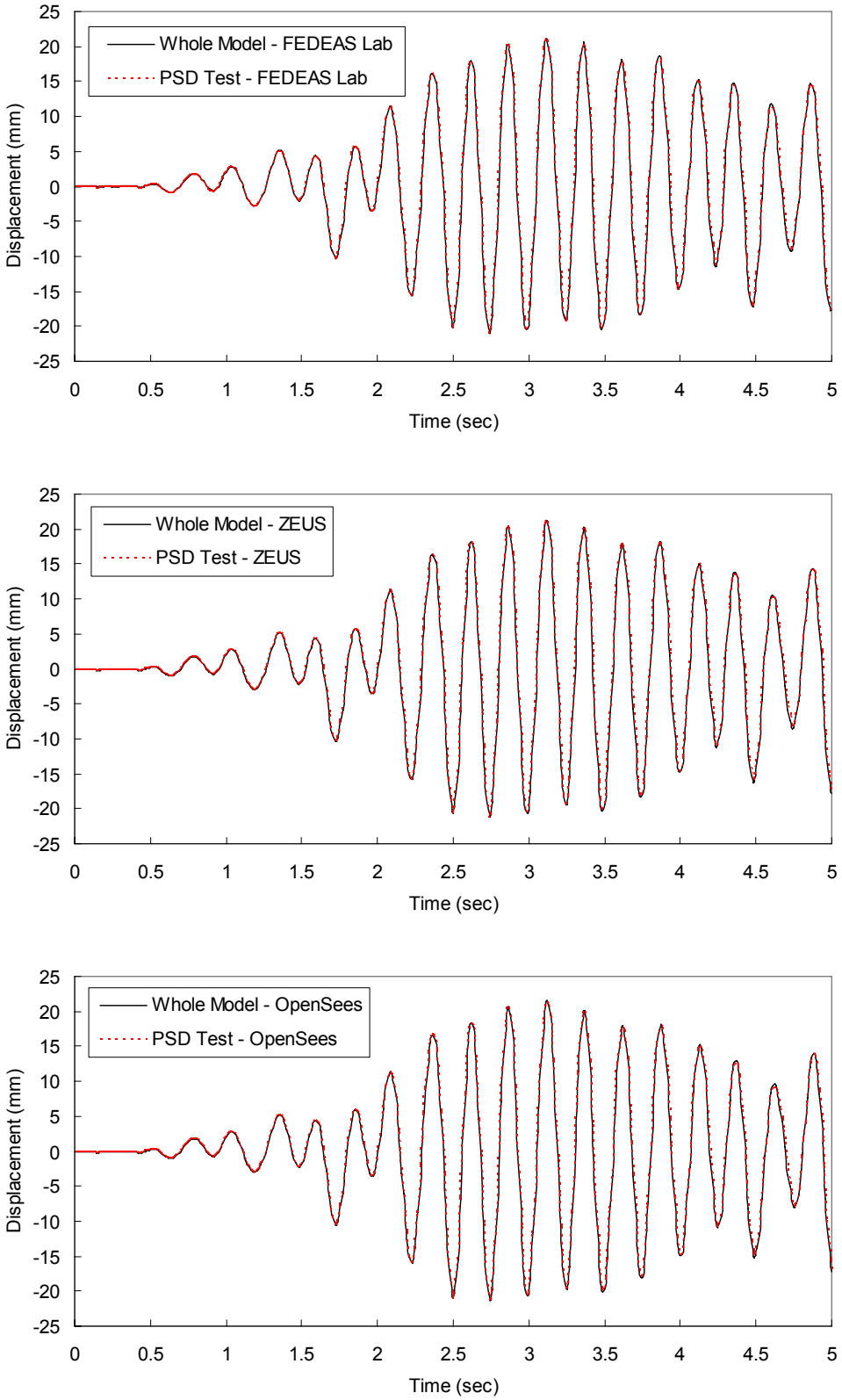


Figure 29 Pseudo dynamic test result – Horizontal displacement of top node

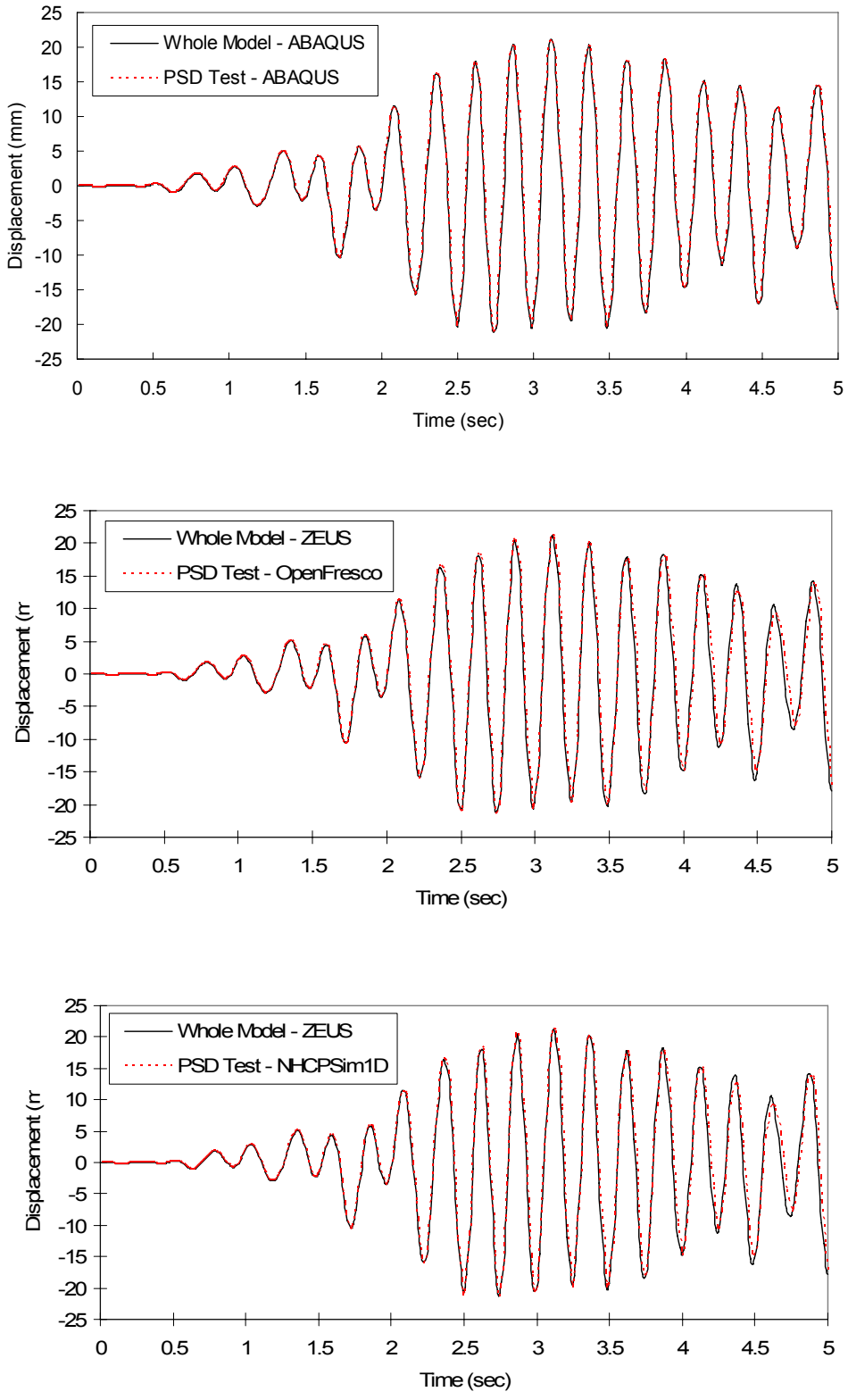


Figure 29 Pseudo dynamic test result – Horizontal displacement of top node - continued

8.2 Inelastic Cantilever Column with Initial Loading – Steel Material

8.2.1 Structural configuration

In the previous example in Section 8.1, the cantilever column is subjected to ground acceleration only. This example shows how to apply initial static forces in the structure. The structural configuration is identical to the example in Section 8.1 except the column is subjected to initial gravity force and bilinear material is used as shown in Figure 30. The material is assumed as elasto-perfectly plastic material. The material's elastic modulus is 200000 N/mm^2 and yield strength is 50 N/mm^2.

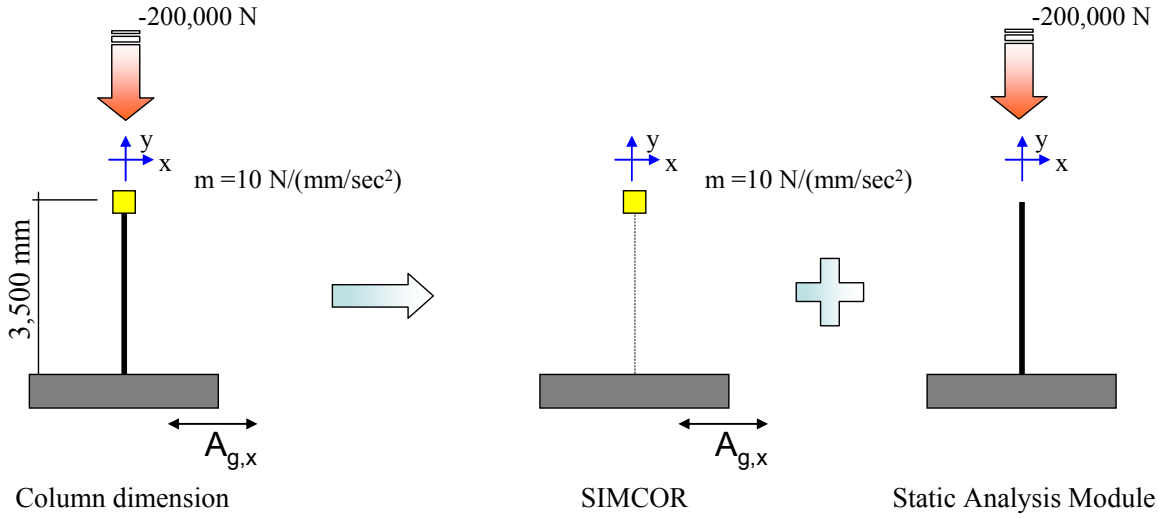


Figure 30 Initial load on cantilever column

The initial loading is applied to the static analysis module. As discussed in Section 3, the PSD test stage can be subdivide into initial stiffness formulation stage, initial loading stage, and dynamic loading stage. **Note that initial loading is defined as time-history load factor as shown in Figure 31**. The load factor should be zero during initial stiffness formulation. Since the structure has two DOFs, the load factor is zero up to the second step. And then the factor increases up to 1 gradually. This incremental application of static loading is to account for the inelastic behavior of structure. In this example, 10 steps are used to apply initial loading. And during this stage, UI-SIMCOR performs inelastic static analysis, not pseudo-dynamic test using α-OS scheme. Right after the initial loading stage, ground acceleration is applied. **The inertial forces are applied from UI-SIMCOR**.

The static analysis module is controlled by displacement. In the previous example, we were interested in x-directional displacement only. In this example, however, we should include y-directional displacement since the initial loading will shorten the column. Thus in the configuration file, the effective DOFs are enabled for x and y direction. From the basics of structural analysis, we cannot control a DOF both for displacement and force.

Since the control point will be displacement controlled in x- and y- direction, the initial loading need to be applied somewhere else. To resolve this problem, a very short frame element is attached on the control point and the initial loading is applied on that element, Figure 32.

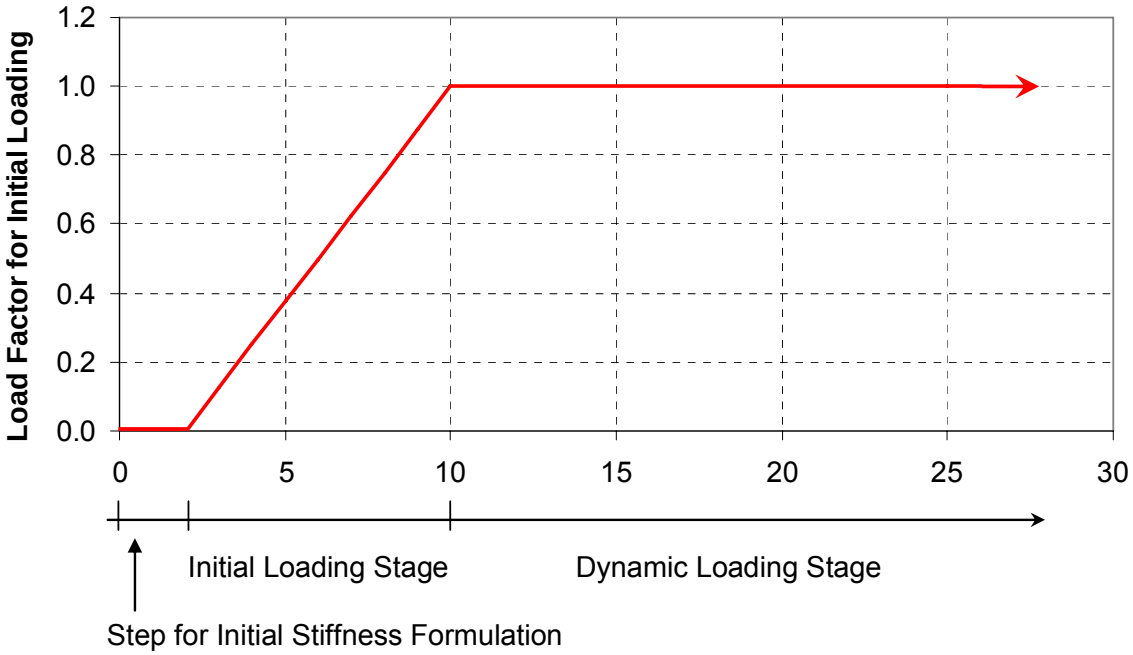


Figure 31 Time-history of initial load factor

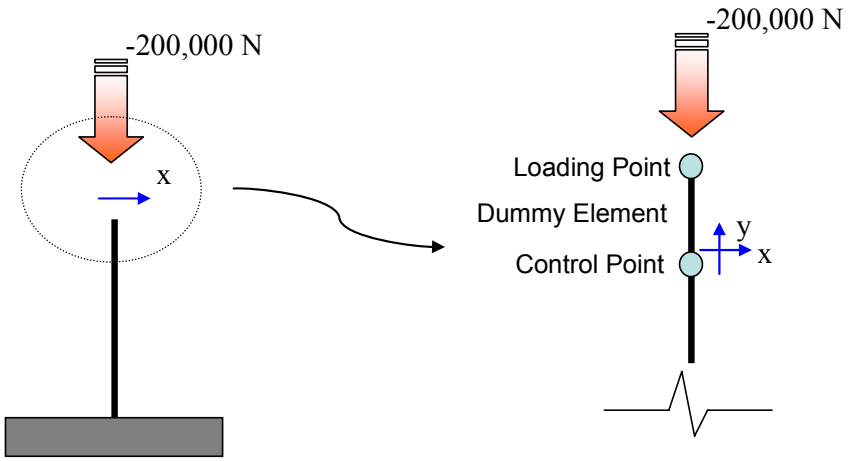


Figure 32 Application of initial loading

8.2.2 Simulation configuration file

The simulation configuration file for this model is identical to previous example in Section 8.1 except that there is static loading step and effective DOFs are defined for x- and y- direction.

C:\SIMCOR\03_Examples\SDOF_InitLoading\00_Coordinator\SimConfig.m

```
function [Sys, MDL, AUX] = SimConfig
MDL = MDL_RF; AUX = MDL_AUX;        % Type definition. Do not delete this line.
% ========================================================================
% Configuration parameters for SDOF experiment
%
% Unit: mm, N, sec
%
% by Oh-Sung Kwon, okwon2@uiuc.edu
% modified by Kyu-Sik Park, kspark@uiuc.edu
% Univ. of Illinois at Urbana Champaign
%
% Last updated on 2007-01-26 11:55PM
% ========================================================================

% ____________________________________________________________________________
%
% Common parameters
% ____________________________________________________________________________

% Ground acceleration file name with extension. The file should contains two
% columns for time and acceleration. The unit of acceleration should be
% consistent with the mass, time, and force. (i.e. mass*acc = force)
Sys.GM_Input = 'elcentro.dat';

% Ground acceleration scale factor. This factor will be multiplied to
% acceleration before starting simulation.
Sys.GM_SC = 9810;

% Direction of ground acceleration. (x, y, or z)
Sys.GM_direction = 'x';

% Integration parameter related to the alpha-OS method.
% Alpha = (0 ~ 1/3). In most cases, SC.Alph = 0.05 worked.
Sys.Alph = 0.05;
Sys.Beta = 1/4*(1+Sys.Alph)^2;
Sys.Gamm = 1/2 + Sys.Alph;

% Evaluate Stiffness?
% Yes (1) to run stiffness evaluation test,
% No  (0) to read stiffness matrix from file. In this case, there should exist
%         stiffness matrices of individual module in the files MDL01_K.txt,
%         MDL02_K.txt, etc.
Sys.Eval_Stiffness = 1;

% Number of initial static loading steps. When there exist static constant
% loading,i.e. gravity forces, apply then in Zeus-NL or OpenSees as a
% incremental loading with 'n' steps. In this file, SimConfig.m, specify the
% number of static steps in the following variable.
Sys.Num_Static_Step = 10;

% Number of dynamic analysis steps
Sys.Num_Dynamic_Step = 500;
```

```
% Dynamic analysis time steps
Sys.dt = 0.01;

% Rayleigh damping, xi_1 and xi_2: Damping ratio, Tn_1, Tn_2: Target period
Sys.xi_1 = 0.00;
Sys.Tn_1 = 0.00;
Sys.xi_2 = 0.00;
Sys.Tn_2 = 0.00;

% Number of Stiffness test
% If stiffness is evaluated through experiment, the evaluation need to be done
% several times and the average of the results are used as the initial
% stiffness. This parameter is used when Sys.Eval_Stiffness = 1
Sys.Num_Test_Stiffness  = 1;

% Enable GUI for SimCor?
% Yes (1) enable the GUI for SimCor
% No  (0) disable the GUI for SimCor
%         Hybrid simulation will be run automatically.
%         Not recommended for the experiment.
Sys.EnableGUI       = 1;         % Use GUI for SimCor

% Number of restoring force modules.
Sys.Num_RF_Module     = 1;

% Number of auxilary modules.
Sys.Num_AUX_Module    = 0;

% Total number of effective nodes. Effective nodes are interface nodes between
% modules and nodes where lumped masses are defined.
Sys.Num_Node        = 1;

% Lumped mass assigned for each DOF for each node.
% Node number = x, y, z, rx, ry, rz directional mass
Sys.Node_Mass{1} = [10, 0, 0, 0, 0, 0];

% ____________________________________________________________________________
%
% Restoring force module configuration
% ____________________________________________________________________________

% Create objects of MDL_RF
MDL(1) = MDL_RF;

% Name of each module.
MDL(1).name = 'STATIC'; % Module ID of this module is 1

% URL of each module
% Format - IP address:port number
% ex) 'http://cee-nsp4.cee.uiuc.edu:11997'
%     for local machine - '127.0.0.1:11997'
MDL(1).URL  = '127.0.0.1:11997';

% Communication protocol for each module.
%       NTCP         : communicate through NEESPOP server
%       TCPIP        : binary communication using TCPIP
%       LabView1     : ASCII communication with LabView plugin format
%                      (Propose-Query-Execute-Query)
%       LabView2     : same as LabView1 but Propose-Query
%       OpenFresco1D : OpenFresco, only 1 DOF is implemented now.
%       NHCP         : NHCP, linear 1 DOF simulation mode, Mini MOST 1 and 2 at
%                      UIUC or SDSC
```

```
MDL(1).protocol = 'LabView2';

% Module 1: STATIC ------------------------------------------------------------
MDL(1).node    = [1];           % Control point node number
MDL(1).EFF_DOF = [1 1 0 0 0 0]; % Effective DOF for CP 1


% Dismplacement for preliminary test for each module
% Del_t: Translation, Del_r: Rotation in radian
MDL(1).DEL_t = 0.005;

MDL(1).DEL_r = 0.002;

% Enable GUI for each module?
% GUI for each module can only display the data.
% GUI for each module can not control the hybrid simulation.
% Yes (1) enable the GUI for each module
% No  (0) disable the GUI for each module
MDL(1).EnableGUI = 1;

% _________________________________________________________________________
%
% Advanced modular parameters
% _________________________________________________________________________
% These parameters need to be redefined for following situations.
%     (1) Different coordinate system between UI-SIMCOR and static module
%     (2) When scale factor needs to be applied either in experiment or
%         simulation
%     (3) To define force and displacement criteria (for tolerance and safety)
%     (4) To trigger camera modules or DAQ system
%     (5) When LBCB at UIUC is used for experiment
%     (6) When NHCP protocol is used
%
% URL of remote site and NHCP mode for NHCP
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).protocol), 'nhcp')
              MDL(i).remote_URL = '127.0.0.1:99999';
              MDL(i).NHCPMode = 'sim1d';
       end
end

% Stiffness for NHCP (Only valid if NHCPMode = 'Sim1D')
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).NHCPMode), 'sim1d')
              MDL(i).NHCPSimK = '1000';
       end
end

% Coordinate transformation. If it needs, the transformation matrix also
% needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).TransM = [];
end

% Scale factor for displacement, rotation, force, moment
% Experimental specimens are not always in full scale. Use this factors to
% apply scale factors.
% The displacement scale factors are multiplied before they are
% sent to module. Measured force and moments are divided with scale factors
% before used in the PSD algorithm.
for i=1:Sys.Num_RF_Module
       MDL(i).ScaleF = [1 1 1 1]; % Module i
end
```

```
% Relaxation check
% If this parameter is 1, UI_SimCor send commend to retrieve data and check
% relaxation just before the execution of proposed command. If it's 1, the
% checking criteria needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).CheckRelax  = 0;          % Module i
       % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement variation ratio (not increment)
  % MDL(i).MES_D_inc = [ a b c d e f
    %                    ...        ];
  % Force variaiton ratio (not increment)
  % MDL(i).MES_F_inc = [ a b c d e f
    %                    ...        ];
end

% Check displacement and force limit
% At every steps, check if the displacement or force are approaching to the
% limitation of the equipments stroke or force capacity.
for i=1:Sys.Num_RF_Module
  MDL(i).CheckLimit  = 0;   % Module i
  % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement increment limit(not ratio)
  % MDL(i).TGT_D_inc = [ a b c d e f
    %                    ...        ];
    % Displacement limit
  % MDL(i).CAP_D_tot = [ a b c d e f
    %                    ...        ];
    % Force limit
  % MDL(i).CAP_F_tot = [ a b c d e f
    %                    ...        ];
    % Displacement tolerance (ratio)
  % MDL(i).TOL_D_inc = [ a b c d e f
    %                    ...        ];
end

% Loading and Boundary Condition Box (LBCB) case. If it's 1, the
% coordinate transformation matrix needs to be provided.
% This can be also used for any other actuator which has diffrence number of
% DOF coordinate with those of UI-SIMCOR

for i=1:Sys.Num_RF_Module
       MDL(i).LBCB = 0;
end

for i=1:Sys.Num_RF_Module
       MDL(i).LBCB_TransM = [];
end

% ____________________________________________________________________________
%
% Auxiliary module configuration
% ____________________________________________________________________________

% AUX(1)                = MDL_AUX;
% AUX(1).URL            = '127.0.0.1:12000';
% AUX(1).protocol       = 'labview1';
% AUX(1).name           = 'Camera';     % Module ID of this mdoule is 1
% AUX(1).Command        = {'displacement' 'z' 3500};
```

Variable Description

Sys.Num_Static_Step

This variable defines the number of static step for initial loading such as gravity as explained in 8.1.2. In this example, Sys.Num_Static_Step is 10 to increases the initial loading gradually as explained in 8.2.1.

8.2.3 Static analysis module configuration

Static analysis modules for this example are identical to previous example except following points.

- The effective DOFs are defined for x- and y- direction.
- Time-history static loading is defined in the model file for ZEUS-NL, OpenSees, and ABAQUS. The time-history load factor is as shown in Figure 31.

FEDEAS Lab, OpenFresco, NHCPSim1D models are not given for this example.

8.2.4 Running simulation

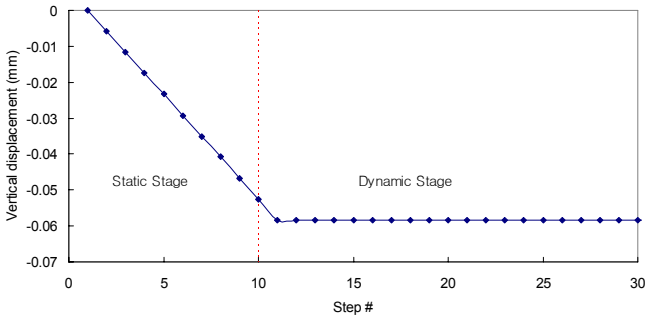
Simulation procedure is identical to Section 8.1.4. Again, please note that the procedure should be followed whenever new analysis starts.

8.2.5 Result and verification

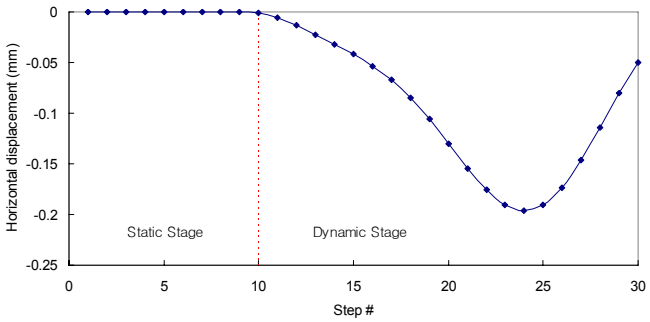
When the column is subjected to gravity force, the column shortens -0.058333 mm. Figures 33 and 34 shows the PSD test result that the vertical displacement reaches -0.058333 mm after 10 static steps and hold the displacement constant during dynamic stage. During static stage, the translational displacement remains zero. Figures 33 and 34 show the vertical and horizontal displacement history from PSD test using OpenSees and ABAQUS as a static module.

When ZEUS-NL is used for the initial loading problem, there could be a fluctuation in translational displacement during static loading stage. It's because ZEUS-NL always accounts for geometric nonlinearity. Thus the estimated stiffness matrix is not diagonal for this problem, and result in inaccurate displacement estimation. The effect of geometric nonlinearity, however, can be controlled by choosing small displacement during initial stiffness formulation stage.

Figure 35 shows very good correspondence between whole model run and PSD test using UI-SIMCOR.

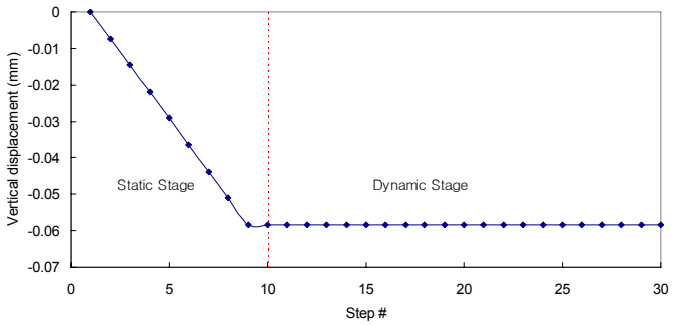


(a) Vertical displacement history

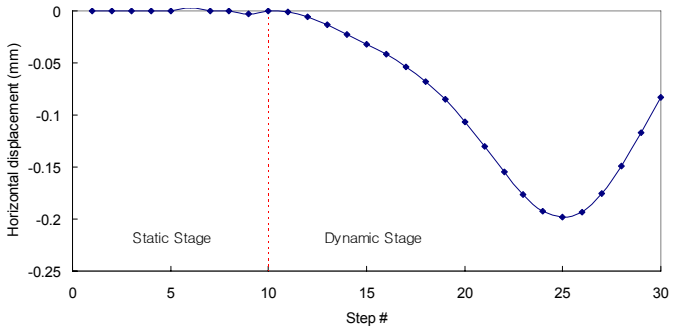


(b) Translational displacement history

Figure 33 Displacement history for initial loading problem - OpenSees



(a) Vertical displacement history



(b) Translational displacement history

Figure 34 Displacement history for initial loading problem – ABAQUS

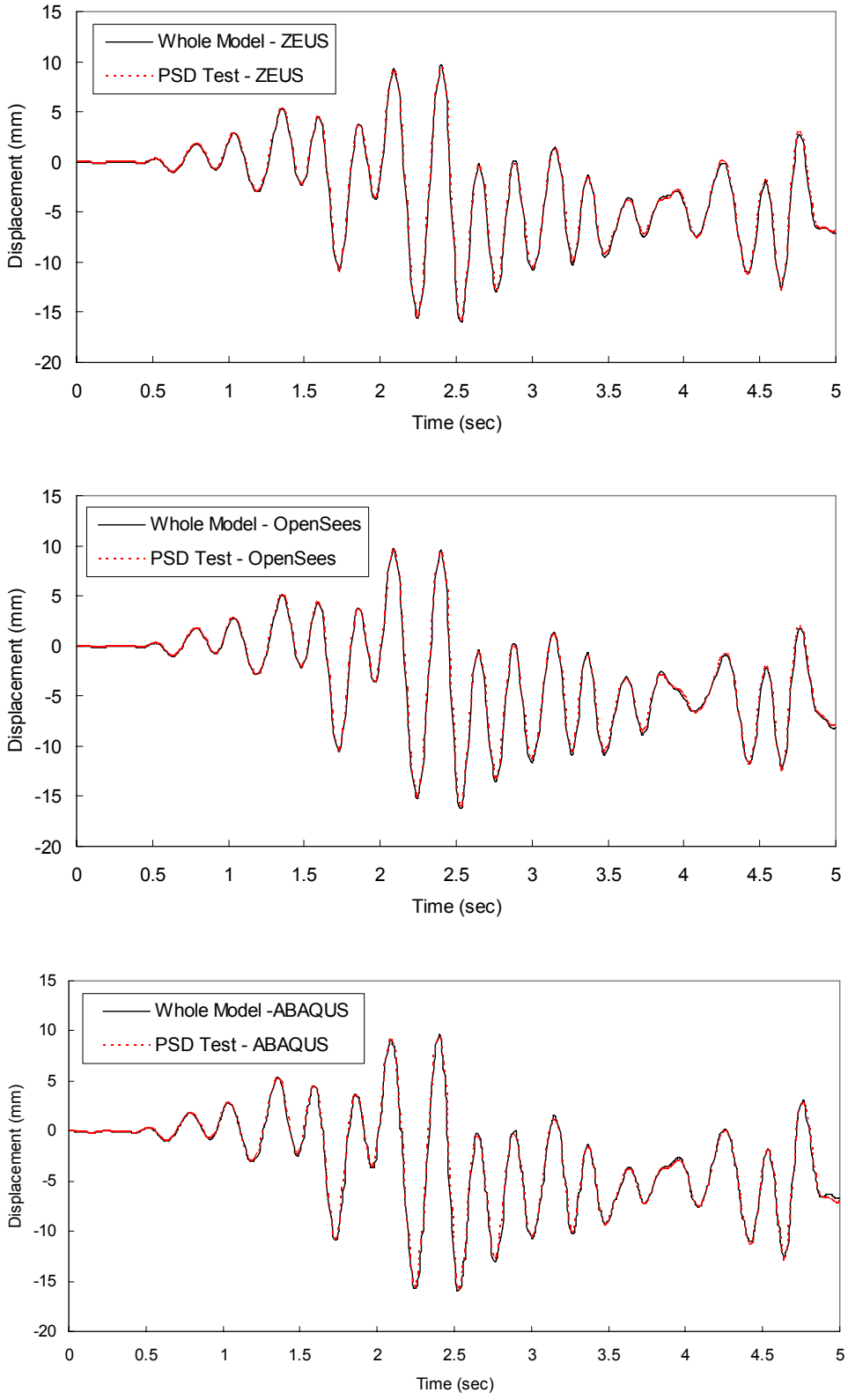


Figure 35 Pseudo dynamic test result – Horizontal displacement of top node

8.3 Inelastic Cantilever Column – Concrete Material

The SDOF system in Section 8.1 is modeled using rectangular concrete section as an example of concrete model. ZEUS-NL and OpenSees has a functionality to mesh the element's section into fibers and apply hysteretic concrete material model. The material properties are given below.

FEDEAS Lab, OpenFresco, and NHCP Simulation Server model is not given for this example. In ABAQUS, concrete material model is very unstable for this example, so ABAUQS model is not given.

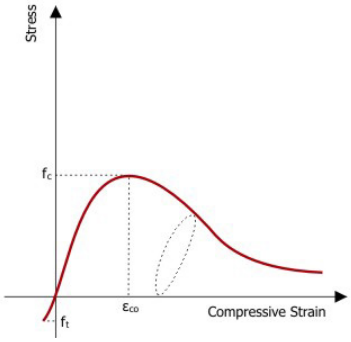
Model property

Material:

Steel: $E=200{,}000\ N/mm^2$
$F_y = 500\ N/mm^2$
Hardening ratio = 3%

Core Conc.: $f_c = 40\ N/mm^2$
$f_t = 4\ N/mm^2$
$\varepsilon_{co} = 0.002$
Confinement factor = 1.2

Cover Conc.: $f_c = 40\ N/mm^2$
$f_t = 4\ N/mm^2$
$\varepsilon_{co} = 0.002$
Confinement factor = 1.0



Section:

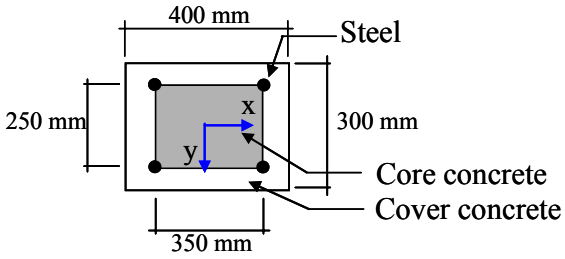


Figure 36 Concrete section properties

All configuration files and running procedures are identical to those of Section 8.1, thus further explanation is not given in this section. Use this example as a reference for modeling concrete section in ZEUS-NL and OpensSees.

Material behaviors and PSD test results are given in Figures 37 and 38.

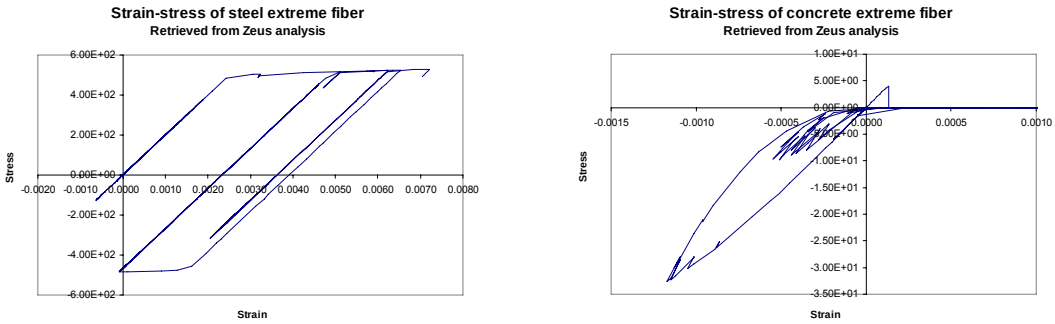


Figure 37 Steel and concrete response history

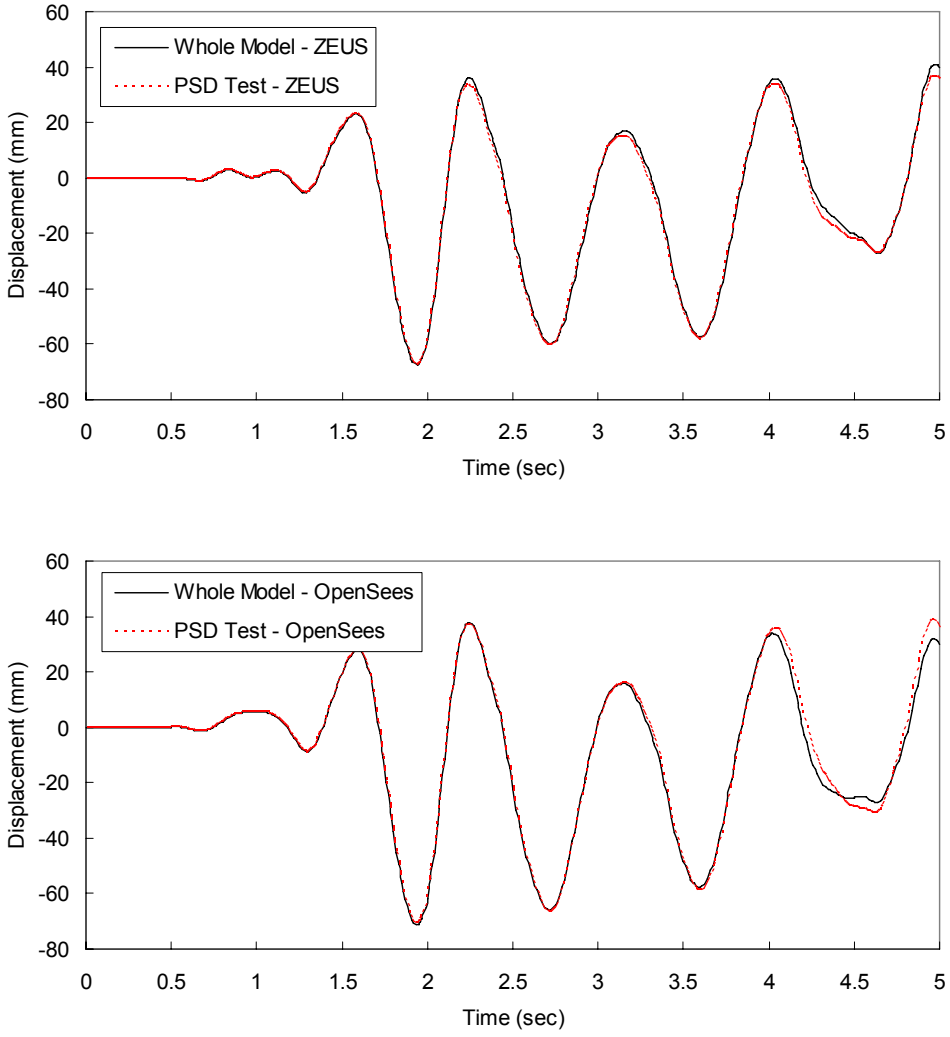


Figure 38 Pseudo dynamic test result – Horizontal displacement of top node

8.4 MOST Example

8.4.1 Structural configuration

The MOST experiment was briefly introduced in Section 4.3 of this document to explain the concept of control points and effective degree of freedoms. The structural properties of the MOST experiment are well documented in the NEESgrid 3.2 documentation (Nakata et. al., 2003). Thus this section focuses on the preparation of the configuration file for UI-SIMCOR and static analysis modules. The former experimental parts and computational parts can be replaced with FEDEAS Lab, ZEUS-NL, OpenSees, and ABAUQS.

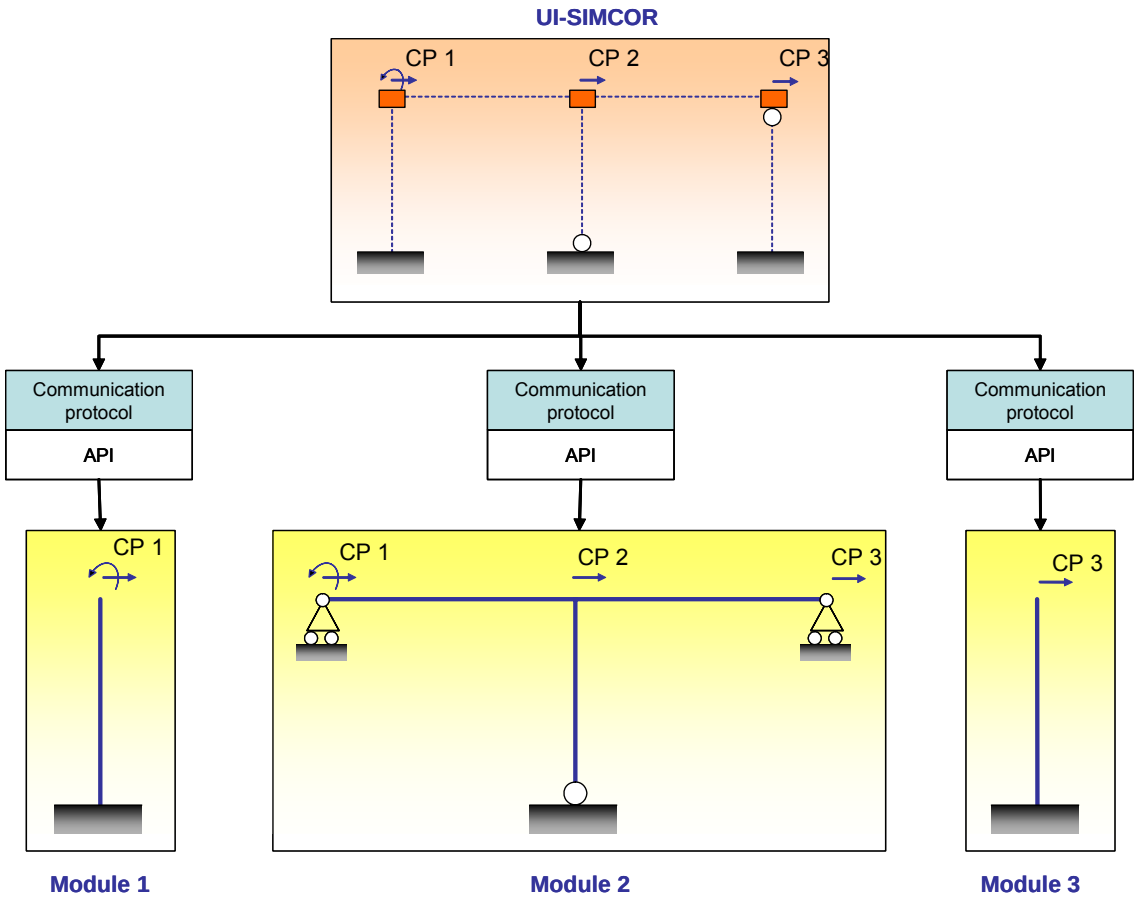


Figure 39 Simulation configuration for MOST example

8.4.2 Simulation configuration file

As opposed to the SDOF example up to Section 8.1, the MOST experiment consists of multiple control points and multiple modules as shown in Figure 39. Thus when the configuration file is prepared for the distributed simulation, the user should specify the address of server where each module communicates and node numbers and effective DOFs where each module is connected. Explanation will be made through the example configuration file for the MOST experiment.

C:\SIMCOR\03_Examples\MOST\00_Coordinator\SimConfig.m

```
function [Sys, MDL, AUX] = SimConfig
MDL = MDL_RF; AUX = MDL_AUX;        % Type definition. Do not delete this line.
% ================================================================================
% Configuration parameters for SDOF experiment
%
% Unit: mm, N, sec
%
% by Oh-Sung Kwon, okwon2@uiuc.edu
% modified by Kyu-Sik Park, kspark@uiuc.edu
% Univ. of Illinois at Urbana Champaign
%
% Last updated on 2007-01-27 11:44AM
% ================================================================================

% ____________________________________________________________________________
%
% Common parameters
% ____________________________________________________________________________

% Ground acceleration file name with extension. The file should contains two
% columns for time and acceleration. The unit of acceleration should be
% consistent with the mass, time, and force. (i.e. mass*acc = force)
Sys.GM_Input = 'acc475C.dat';

% Ground acceleration scale factor. This factor will be multiplied to
% acceleration before starting simulation.
Sys.GM_SC = 9.81;

% Direction of ground acceleration. (x, y, or z)
Sys.GM_direction = 'x';

% Integration parameter related to the alpha-OS method.
% Alpha = (0 ~ 1/3). In most cases, SC.Alph = 0.05 worked.
Sys.Alph = 0.05;
Sys.Beta = 1/4*(1+Sys.Alph)^2;
Sys.Gamm = 1/2 + Sys.Alph;

% Evaluate Stiffness?
% Yes (1) to run stiffness evaluation test,
% No  (0) to read stiffness matrix from file. In this case, there should exist
%         stiffness matrices of individual module in the files MDL01_K.txt,
%         MDL02_K.txt, etc.
Sys.Eval_Stiffness = 1;

% Number of initial static loading steps. When there exist static constant
% loading,i.e. gravity forces, apply then in Zeus-NL or OpenSees as a
% incremental loading with 'n' steps. In this file, SimConfig.m, specify the
```

```
% number of static steps in the following variable.
Sys.Num_Static_Step = 0;

% Number of dynamic analysis steps
Sys.Num_Dynamic_Step = 500;

% Dynamic analysis time steps
Sys.dt = 0.01;

% Rayleigh damping, xi_1 and xi_2: Damping ratio, Tn_1, Tn_2: Target period
Sys.xi_1 = 0.00;
Sys.Tn_1 = 0.00;
Sys.xi_2 = 0.00;
Sys.Tn_2 = 0.00;

% Number of Stiffness test
% If stiffness is evaluated through experiment, the evaluation need to be done
% several times and the average of the results are used as the initial
% stiffness. This parameter is used when Sys.Eval_Stiffness = 1
Sys.Num_Test_Stiffness  = 1;

% Enable GUI for SimCor?
% Yes (1) enable the GUI for SimCor
% No  (0) disable the GUI for SimCor
%         Hybrid simulation will be run automatically.
%         Not recommended for the experiment.
Sys.EnableGUI       = 1;         % Use GUI for SimCor

% Number of restoring force modules.
Sys.Num_RF_Module     = 3;

% Number of auxilary modules.
Sys.Num_AUX_Module    = 0;

% Total number of effective nodes. Effective nodes are interface nodes between
% modules and nodes where lumped masses are defined.
Sys.Num_Node        = 3;

% Lumped mass assigned for each DOF for each node.
% Node number = x, y, z, rx, ry, rz directional mass
Sys.Node_Mass{1} = [2.54628081981000, 0, 0, 0, 0, 0];
Sys.Node_Mass{2} = [5.49705587697000, 0, 0, 0, 0, 0];
Sys.Node_Mass{3} = [2.54628081981000, 0, 0, 0, 0, 0];


% ____________________________________________________________________________
%
% Restoring force module configuration
% ____________________________________________________________________________

% Create objects of MDL_RF
MDL(1) = MDL_RF;
MDL(2) = MDL_RF;
MDL(3) = MDL_RF;

% Name of each module.
MDL(1).name = 'LeftCol'; % Module ID of this module is 1
MDL(2).name = 'Middle'; % Module ID of this module is 2
MDL(3).name = 'RightCol'; % Module ID of this module is 3

% URL of each module
MDL(1).URL  = '127.0.0.1:11997';
MDL(2).URL  = '127.0.0.1:11998';
```

```
MDL(3).URL  = '127.0.0.1:11999';

% Communication protocol for each module.
%       NTCP         : communicate through NEESPOP server
%       TCPIP        : binary communication using TCPIP
%       LabView1     : ASCII communication with LabView plugin format
%                      (Propose-Query-Execute-Query)
%       LabView2     : same as LabView1 but Propose-Query
%       OpenFresco1D : OpenFresco, only 1 DOF is implemented now.
%       NHCP         : NHCP, linear 1 DOF simulation mode, Mini MOST 1 and 2 at
%                      UIUC or SDSC
MDL(1).protocol = 'LabView2';
MDL(2).protocol = 'LabView2';
MDL(3).protocol = 'LabView2';


% Module 1: Left column ---------------------------------------------------
MDL(1).node    = [1];           % Control point node number
MDL(1).EFF_DOF = [1 0 0 0 0 1]; % Effective DOF for CP 1


% Module 2: Middle column and beams ---------------------------------------
MDL(2).node    = [1 2 3];       % Control point node number
MDL(2).EFF_DOF = [1 0 0 0 0 1   % Effective DOF for CP 1
                  1 0 0 0 0 0    % Effective DOF for CP 2
                  1 0 0 0 0 0];  % Effective DOF for CP 3

% Module 3: Right column --------------------------------------------------
MDL(3).node    = [3];           % Control point node number
MDL(3).EFF_DOF = [1 0 0 0 0 0]; % Effective DOF for CP 3

% Dismplacement for preliminary test for each module
% Del_t: Translation, Del_r: Rotation in radian
MDL(1).DEL_t = 0.005;
MDL(2).DEL_t = 0.005;
MDL(3).DEL_t = 0.005;

MDL(1).DEL_r = 0.002;
MDL(2).DEL_r = 0.002;
MDL(3).DEL_r = 0.002;

% Enable GUI for each module?
% GUI for each module can only display the data.
% GUI for each module can not control the hybrid simulation.
% Yes (1) enable the GUI for each module
% No  (0) disable the GUI for each module
MDL(1).EnableGUI = 1;
MDL(2).EnableGUI = 1;
MDL(3).EnableGUI = 1;

% _____________________________________________________________________________
%
% Advanced modular parameters
% _____________________________________________________________________________
% These parameters need to be redefined for following situations.
%     (1) Different coordinate system between UI-SIMCOR and static module
%     (2) When scale factor needs to be applied either in experiment or
%         simulation
%     (3) To define force and displacement criteria (for tolerance and safety)
%     (4) To trigger camera modules or DAQ system
%     (5) When LBCB at UIUC is used for experiment
%     (6) When NHCP protocol is used
%
```

```
% URL of remote site and NHCP mode for NHCP
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).protocol), 'nhcp')
              MDL(i).remote_URL = '127.0.0.1:99999';
              MDL(i).NHCPMode = 'sim1d';
       end
end

% Stiffness for NHCP (Only valid if NHCPMode = 'Sim1D')
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).NHCPMode), 'sim1d')
              MDL(i).NHCPSimK = '1000';
       end
end

% Coordinate transformation. If it needs, the transformation matrix also
% needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).TransM = [];
end

% Scale factor for displacement, rotation, force, moment
% Experimental specimens are not always in full scale. Use this factors to
% apply scale factors.
% The displacement scale factors are multiplied before they are
% sent to module. Measured force and moments are divided with scale factors
% before used in the PSD algorithm.
for i=1:Sys.Num_RF_Module
       MDL(i).ScaleF = [1 1 1 1]; % Module i
end

% Relaxation check
% If this parameter is 1, UI_SimCor send commend to retrieve data and check
% relaxation just before the execution of proposed command. If it's 1, the
% checking criteria needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).CheckRelax  = 0;          % Module i
       % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement variation ratio (not increment)
  % MDL(i).MES_D_inc = [ a b c d e f
    %                     ...        ];
  % Force variaiton ratio (not increment)
  % MDL(i).MES_F_inc = [ a b c d e f
    %                     ...        ];
end

% Check displacement and force limit
% At every steps, check if the displacement or force are approaching to the
% limitation of the equipments stroke or force capacity.
for i=1:Sys.Num_RF_Module
  MDL(i).CheckLimit  = 0;   % Module i
  % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement increment limit(not ratio)
  % MDL(i).TGT_D_inc = [ a b c d e f
    %                     ...        ];
    % Displacement limit
  % MDL(i).CAP_D_tot = [ a b c d e f
    %                     ...        ];
    % Force limit
```

```
  % MDL(i).CAP_F_tot = [ a b c d e f
    %                    ...        ];
    % Displacement tolerance (ratio)
  % MDL(i).TOL_D_inc = [ a b c d e f
    %                    ...        ];
end

% Loading and Boundary Condition Box (LBCB) case. If it's 1, the
% coordinate transformation matrix needs to be provided.
% This can be also used for any other actuator which has diffrence number of
% DOF coordinate with those of UI-SIMCOR

for i=1:Sys.Num_RF_Module
       MDL(i).LBCB = 0;
end

for i=1:Sys.Num_RF_Module
       MDL(i).LBCB_TransM = [];
end

% ____________________________________________________________________________
%
% Auxiliary module configuration
% ____________________________________________________________________________

% AUX(1)                = MDL_AUX;
% AUX(1).URL            = '127.0.0.1:12000';
% AUX(1).protocol       = 'labview1';
% AUX(1).name           = 'Camera';     % Module ID of this mdoule is 1
% AUX(1).Command        = {'displacement' 'z' 3500};
```

Variable Description

Most variables in SimConfig.m are explained in Section 8.1 for SDOF system. In this section, variables that are related to multiple control points and multiple modules are further explained.

Sys.Num_RF_Module

In this example, the MOST experiment will be simulated using three analysis modules. Thus Sys.Num_RF_Module is 3. Each module has its own module number. The one representing left column is assigned number 1, beams and middle column is number 2, and the right column are designated as number 3.

Sys.Num_Node

The MOST experiment consists of three control points. As discussed in Section 4, control points are nodes with lumped masses or with DOFs of interest.

Sys.Node_Mass{*i*}

Lumped masses are assigned for each node. In this example it is assumed that only x-directional masses exist.

MDL(*i*).name

Since there are three modules, three names, i. e., 'LeftCol', 'Middle', and 'RightCol' for each module are defined in the configuration file.

MDL(*i*).URL

Since there are three modules, three URL for communication are defined in the configuration file.

MDL(*i*).protocol

Since there are three modules, three protocols for each module are defined in the configuration file.

MDL(*i*).node

This variable defines the control points that are connected to a certain module. In Figure 22, the left column is connected to control point 1 only. Thus in the configuration file, MDL(1).node = [1]. The second module, where beams and middle-column are defined, is connected to three control points. Thus in the configuration file, MDL(2).node = [1 2 3]. Third module has only one control point, #3.

MDL(*i*).EFF_DOF

Effective DOFs also need to be defined for each control point for each module. In module 1, x-translational and rotational DOFs are effective as shown in Figure 23. Thus Effective DOFs are [1 0 0 0 0 1].

MDL(*i*).DEL_t, and MDL(*i*).DEL _r

There are three control points in this example, so displacement level for the test for initial stiffness formulation should defined for each module.

8.4.3 Static analysis module configuration

The configuration files for static analysis module are similar to those for SDOF system. Thus further explanation is not given in this section. In the folder, *C:\SIMCOR\03_Examples\MOST,* there are sub folders containing the structural model file and module configuration files for FEDEAS Lab, ZEUS-NL, OpenSees, and ABAQUS.

There is one thing that needs attention. When ZEUS-NL is used as a static analysis module in which there are multiple control points or multiple DOFs for single control points, the static time history load should be defined in the order of control point number and DOFs number. For instance, the left column of the MOST experiment consists of one control point in which two DOFs are used. In ZEUS-NL input file, time history load should be defined in the order of control points and then DOFs.

```
1: time.history.loads
2:   nod.name     direction     type           crv.name     value
3:   n102         x             displacement   CV           1.
```

```
4:   n102        rz           displacement   CV          1.
```

In other words, the third and fourth line in the above script cannot be swapped. Furthermore, the type of protocol and port number should be identical between simulation coordinator and each module configuration file.

This and following SAC examples need to run three ABAQUS simultaneously. However, it is impossible to run three ABAUQS under limited license. Instead of running three ABAQUS in one computer, multiple computers can be used for example which has modules more than three.

8.4.4 Running simulation

MOST experiment requires four processes, one for UI-SIMCOR and the other three for static analysis modules. UI-SIMCOR requires a MATLAB. If FEDEAS Lab or ABAQUS models are going to be used as a static analysis module, another MATLAB should be started. If all three modules are FEDEAS Lab or ABAQUS models, then three another MATLAB processes should be started. If ZEUS-NL or OpenSees model is used, then NEES-SAM needs to be run.

The four processes can be run either in a single computer or in a multiple computers. As long as network configuration is set correctly, the four processes can run in four computers. The procedure for running this example is as given below.

1. Prepare configuration file. The network setting (e. g., port number in each static analysis module configuration file should be identical with the simulation coordinator file.) should be carefully set.
2. Prepare static module
    a. If FEDEA Lab or ABAQUS is used,
        i. Start a MATLAB **for each module**
        ii. For FEDEAS Lab: Change current directory to the folder where FedeasCFG.m and the model file of each module exist.
        For ABAQUS: Change current directory to the folder where AbaqusCFG.m and the model file of each module exist.
        iii. For FEDEAS Lab: Run FEDEAS Lab by inputting following command
        NEES_FL_LabView2 [enter] for LabView2 protocol.
        For ABAQUS: Run ABAQUS by inputting following command
        NEES_Abaqus_LabView2 [enter] for LabView2 protocol.
    b. If ZEUS-NL or OpenSees are used with NEES-SAM
        i. Start NEES-SAM by double clicking NEESSAM_TCPIP.exe (tcpip protocol) or NEESSAM_LabView1.exe (LabVIEW1 protocol) or NEESSAM_LabView2.exe (LabVIEW2 protocol) **for each module**.

ii. Select the configuration file from the folder where configuration file and model file exist.
iii. Check the open port and status.

3. Run one MATLAB for UI-SIMCOR. Change current directory to the folder where SimConfig.m and ground motion file is located. Run UI-SIMCOR by inputting following command.

UI_SIMCOR [enter]

8.4.5 Result and verification

MOST and SAC (next section) examples use artificial earthquake as shown in Figure 40. The results of PSD test using UI-SIMCOR are very good correspondence with those of whole model run as shown in Figure 41.

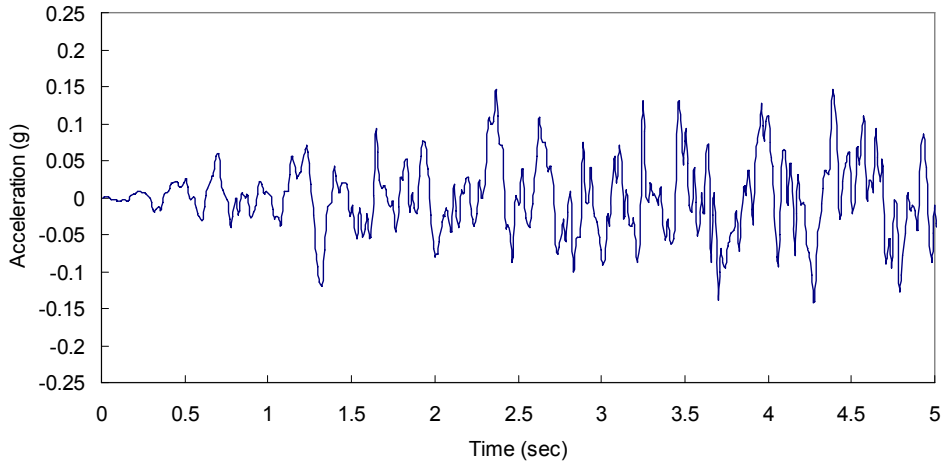


Figure 40 Artificial earthquake

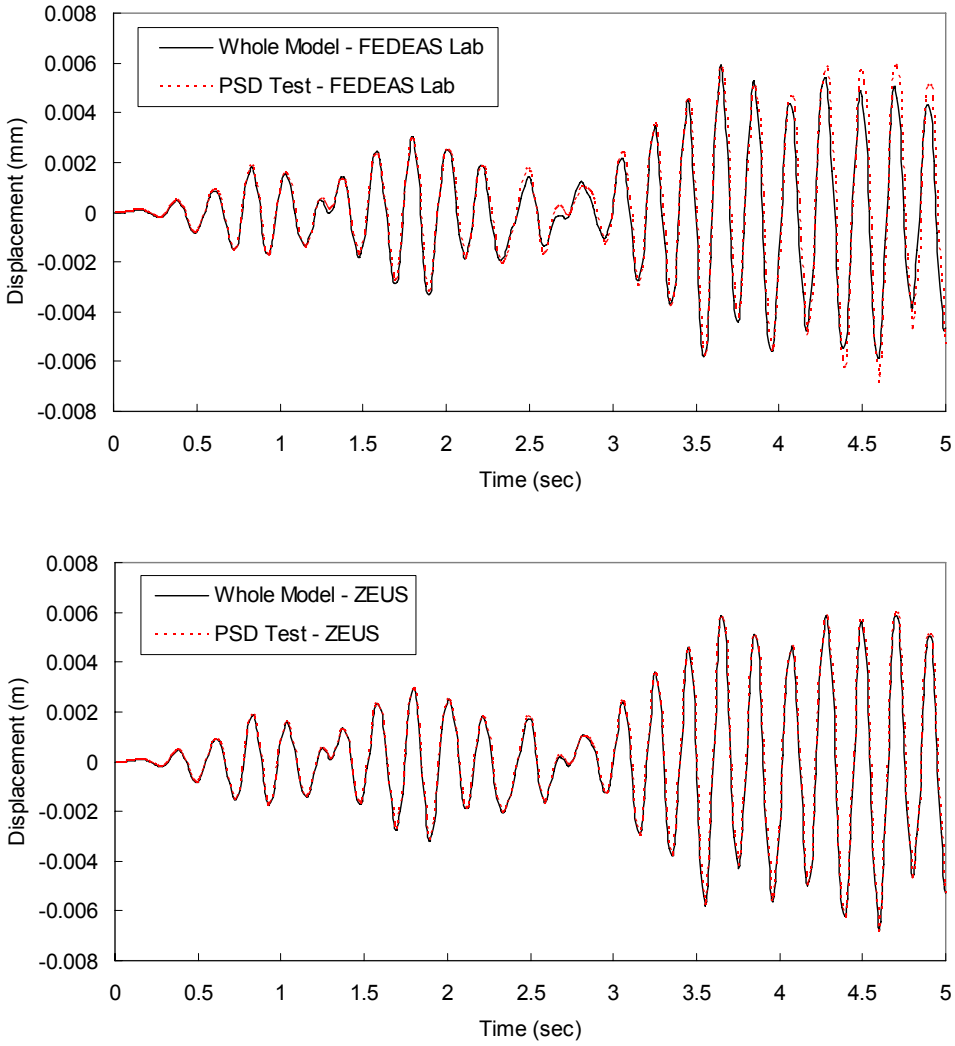


Figure 40 Pseudo dynamic test result – Horizontal displacement at control point 1

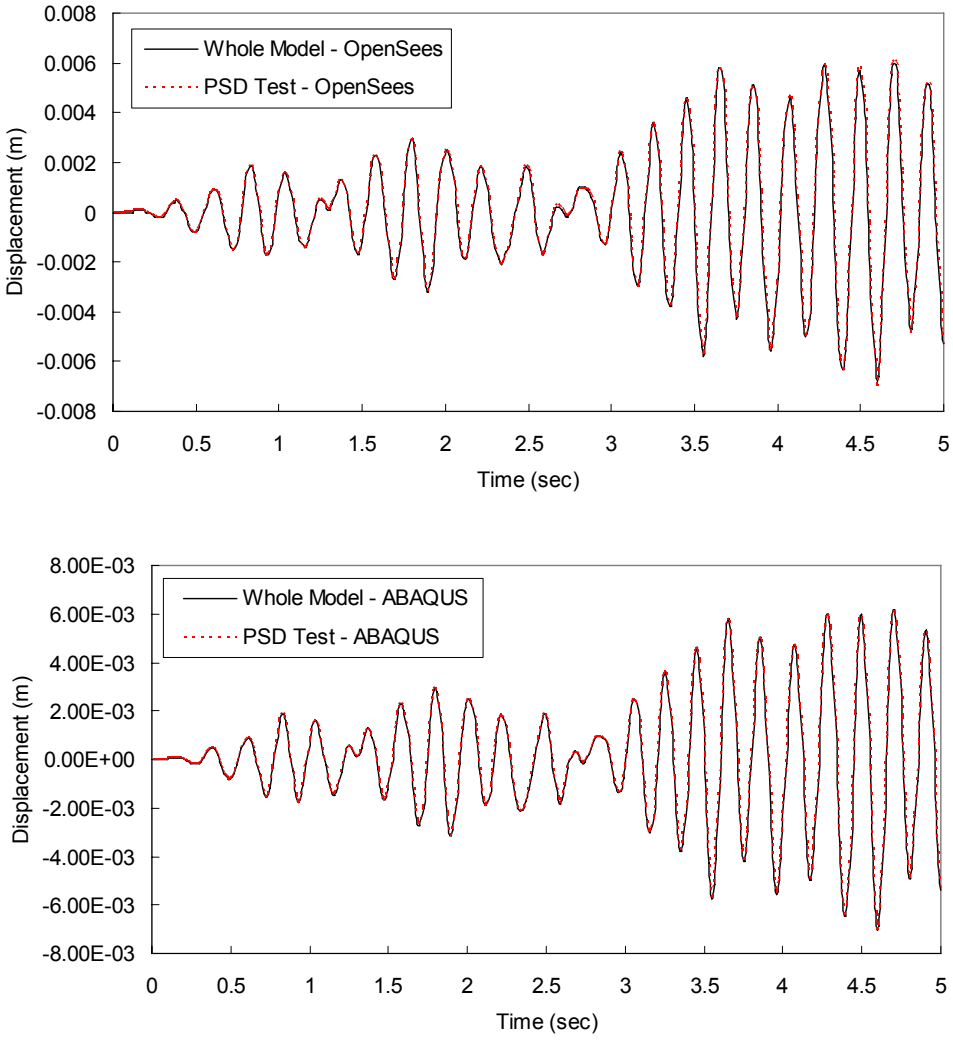


Figure 40 Pseudo dynamic test result – Horizontal displacement at control point 1 - continued

8.5 SAC Three-Story Steel Structure

8.5.1 Structural configuration

A three-story steel structure model is presented in this section. The structure is consists of three-bay and three-story. Whole structural model is given for FEDEAS Lab, ZEUS-NL, and ABAQUS. Then the whole structural model is subdivided into three modules, one external beam-column joint, one internal column, and remaining frame. Procedure for configuration of network and running the simulation are same with the previous examples.

The whole structure is three-story and three-bay as shown in Figure 42. Lumped masses are assigned to every beam-column joint. One external beam-column joint and one internal column will be physically tested. In the whole model, there is a lumped mass at the external beam-column joint that will be tested. As discussed in Section 4, all nodes with mass or with DOFs of interest should be defined in the SimConfig.m file and those nodes will be displacement controlled. The external beam-column joint, however, will be tested using only two control points. Thus, the lumped mass in the tested beam-column joint is shifted to connection point as shown in Figure 42. The shifting of this mass has little effect on the response of the structure since the inertial forces are acting on x-direction only and the structure deformation is caused mainly by flexure not by the axial compression or elongation of beams. The connection points between two modules are also defined as control points. Thus in SimConfig.m file, there are total 14 control points.

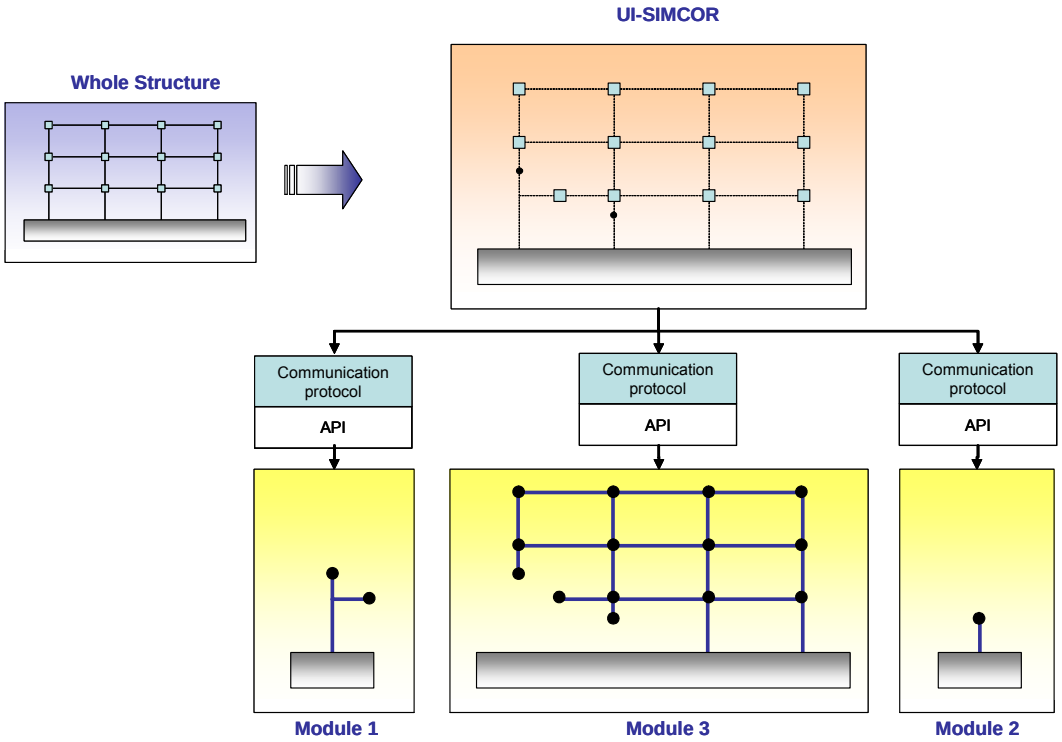


Figure 42 Substructure PSD Test Modeling

8.5.2 Simulation configuration file

C:\SIMCOR\03_Examples\SAC\00_Coordinator\SimConfig.m

```
function [Sys, MDL, AUX] = SimConfig
MDL = MDL_RF; AUX = MDL_AUX;        % Type definition. Do not delete this line.
% ========================================================================
% Configuration parameters for SDOF experiment
%
% Unit: m, kN, sec
%
% by Oh-Sung Kwon, okwon2@uiuc.edu
% modified by Kyu-Sik Park, kspark@uiuc.edu
% Univ. of Illinois at Urbana Champaign
%
% Last updated on 2007-01-27 12:03AM
% ========================================================================

% _____________________________________________________________________________
%
% Common parameters
% _____________________________________________________________________________

% Ground acceleration file name with extension. The file should contains two
% columns for time and acceleration. The unit of acceleration should be
% consistent with the mass, time, and force. (i.e. mass*acc = force)
Sys.GM_Input = 'acc475C.dat';

% Ground acceleration scale factor. This factor will be multiplied to
% acceleration before starting simulation.
Sys.GM_SC = 32.2;

% Direction of ground acceleration. (x, y, or z)
Sys.GM_direction = 'x';

% Integration parameter related to the alpha-OS method.
% Alpha = (0 ~ 1/3). In most cases, SC.Alph = 0.05 worked.
Sys.Alph = 0.05;
Sys.Beta = 1/4*(1+Sys.Alph)^2;
Sys.Gamm = 1/2 + Sys.Alph;

% Evaluate Stiffness?
% Yes (1) to run stiffness evaluation test,
% No  (0) to read stiffness matrix from file. In this case, there should exist
%         stiffness matrices of individual module in the files MDL01_K.txt,
%         MDL02_K.txt, etc.
Sys.Eval_Stiffness = 1;

% Number of initial static loading steps. When there exist static constant
% loading,i.e. gravity forces, apply then in Zeus-NL or OpenSees as a
% incremental loading with 'n' steps. In this file, SimConfig.m, specify the
% number of static steps in the following variable.
Sys.Num_Static_Step = 0;

% Number of dynamic analysis steps
Sys.Num_Dynamic_Step = 500;

% Dynamic analysis time steps
Sys.dt = 0.01;

% Rayleigh damping, xi_1 and xi_2: Damping ratio, Tn_1, Tn_2: Target period
```

```
Sys.xi_1 = 0.03;
Sys.Tn_1 = 1.064;
Sys.xi_2 = 0.03;
Sys.Tn_2 = 0.338;

% Number of Stiffness test
% If stiffness is evaluated through experiment, the evaluation need to be done
% several times and the average of the results are used as the initial
% stiffness. This parameter is used when Sys.Eval_Stiffness = 1
Sys.Num_Test_Stiffness  = 1;

% Enable GUI for SimCor?
% Yes (1) enable the GUI for SimCor
% No  (0) disable the GUI for SimCor
%         Hybrid simulation will be run automatically.
%         Not recommended for the experiment.
Sys.EnableGUI       = 1;         % Use GUI for SimCor

% Number of restoring force modules.
Sys.Num_RF_Module     = 3;

% Number of auxilary modules.
Sys.Num_AUX_Module    = 0;

% Total number of effective nodes. Effective nodes are interface nodes between
% modules and nodes where lumped masses are defined.
Sys.Num_Node        = 14;

% Lumped mass assigned for each DOF for each node.
% Node number = x, y, z, rx, ry, rz directional mass
Sys.Node_Mass{1}  = [8.875,  0, 0, 0, 0, 0];
Sys.Node_Mass{2}  = [8.875,  0, 0, 0, 0, 0];
Sys.Node_Mass{3}  = [8.875,  0, 0, 0, 0, 0];
Sys.Node_Mass{4}  = [8.875,  0, 0, 0, 0, 0];
Sys.Node_Mass{5}  = [8.1875, 0, 0, 0, 0, 0];
Sys.Node_Mass{6}  = [8.1875, 0, 0, 0, 0, 0];
Sys.Node_Mass{7}  = [8.1875, 0, 0, 0, 0, 0];
Sys.Node_Mass{8}  = [8.1875, 0, 0, 0, 0, 0];
Sys.Node_Mass{9}  = [0,      0, 0, 0, 0, 0];
Sys.Node_Mass{10} = [8.1875, 0, 0, 0, 0, 0];
Sys.Node_Mass{11} = [8.1875, 0, 0, 0, 0, 0];
Sys.Node_Mass{12} = [8.1875, 0, 0, 0, 0, 0];
Sys.Node_Mass{13} = [8.1875, 0, 0, 0, 0, 0];
Sys.Node_Mass{14} = [0,      0, 0, 0, 0, 0];

% ____________________________________________________________________________
%
% Restoring force module configuration
% ____________________________________________________________________________

% Create objects of MDL_RF
MDL(1) = MDL_RF;
MDL(2) = MDL_RF;
MDL(3) = MDL_RF;

% Name of each module.
MDL(1).name = 'Joint'; % Module ID of this module is 1
MDL(2).name = 'Column'; % Module ID of this module is 2
MDL(3).name = 'Frame'; % Module ID of this module is 3

% URL of each module
% Format - IP address:port number
% ex) 'http://cee-nsp4.cee.uiuc.edu:11997'
```

```
%     for local machine - '127.0.0.1:11997'
MDL(1).URL  = '127.0.0.1:11997';
MDL(2).URL  = '127.0.0.1:11998';
MDL(3).URL  = '127.0.0.1:11999';

% Communication protocol for each module.
%       NTCP         : communicate through NEESPOP server
%       TCPIP        : binary communication using TCPIP
%       LabView1     : ASCII communication with LabView plugin format
%                      (Propose-Query-Execute-Query)
%       LabView2     : same as LabView1 but Propose-Query
%       OpenFresco1D : OpenFresco, only 1 DOF is implemented now.
%       NHCP         : NHCP, linear 1 DOF simulation mode, Mini MOST 1 and 2 at
%                      UIUC or SDSC
MDL(1).protocol = 'LabView2';
MDL(2).protocol = 'LabView2';
MDL(3).protocol = 'LabView2';

% Module 1: Joint -----------------------------------------------------------
MDL(1).node    = [9 10];          % Control point node number
MDL(1).EFF_DOF = [1 1 0 0 0 1     % Effective DOF for CP 9
                  1 1 0 0 0 1];   % Effective DOF for CP 10

% Module 2: Column ----------------------------------------------------------
MDL(2).node    = [14];            % Control point node number
MDL(2).EFF_DOF = [1 1 0 0 0 1];   % Effective DOF for CP 14


% Module 3: Frame -----------------------------------------------------------
MDL(3).node    = [1 2 3 4 5 6 7 8 9 10 11 12 13 14];          % Control point
node number
MDL(3).EFF_DOF = [1 1 0 0 0 0     % Effective DOF for CP 1 ~ 14
                  1 1 0 0 0 0
                  1 1 0 0 0 0
                  1 1 0 0 0 0
                  1 1 0 0 0 0
                  1 1 0 0 0 0
                  1 1 0 0 0 0
                  1 1 0 0 0 1
                  1 1 0 0 0 1
                  1 1 0 0 0 0
                  1 1 0 0 0 0
                  1 1 0 0 0 0
                  1 1 0 0 0 1];

% Dismplacement for preliminary test for each module
% Del_t: Translation, Del_r: Rotation in radian
MDL(1).DEL_t = 1e-5;
MDL(2).DEL_t = 1e-5;
MDL(3).DEL_t = 1e-5;

MDL(1).DEL_r = 1e-5;
MDL(2).DEL_r = 1e-5;
MDL(3).DEL_r = 1e-5;

% Enable GUI for each module?
% GUI for each module can only display the data.
% GUI for each module can not control the hybrid simulation.
% Yes (1) enable the GUI for each module
% No  (0) disable the GUI for each module
MDL(1).EnableGUI = 1;
MDL(2).EnableGUI = 1;
```

```
MDL(3).EnableGUI = 1;


% ____________________________________________________________________________
%
% Advanced modular parameters
% ____________________________________________________________________________
% These parameters need to be redefined for following situations.
%     (1) Different coordinate system between UI-SIMCOR and static module
%     (2) When scale factor needs to be applied either in experiment or
%         simulation
%     (3) To define force and displacement criteria (for tolerance and safety)
%     (4) To trigger camera modules or DAQ system
%     (5) When LBCB at UIUC is used for experiment
%     (6) When NHCP protocol is used
%
% URL of remote site and NHCP mode for NHCP
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).protocol), 'nhcp')
              MDL(i).remote_URL = '127.0.0.1:99999';
              MDL(i).NHCPMode = 'sim1d';
       end
end

% Stiffness for NHCP (Only valid if NHCPMode = 'Sim1D')
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).NHCPMode), 'sim1d')
              MDL(i).NHCPSimK = '1000';
       end
end

% Coordinate transformation. If it needs, the transformation matrix also
% needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).TransM = [];
end

% Scale factor for displacement, rotation, force, moment
% Experimental specimens are not always in full scale. Use this factors to
% apply scale factors.
% The displacement scale factors are multiplied before they are
% sent to module. Measured force and moments are divided with scale factors
% before used in the PSD algorithm.
for i=1:Sys.Num_RF_Module
       MDL(i).ScaleF = [1 1 1 1]; % Module i
end

% Relaxation check
% If this parameter is 1, UI_SimCor send commend to retrieve data and check
% relaxation just before the execution of proposed command. If it's 1, the
% checking criteria needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).CheckRelax  = 0;          % Module i
       % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement variation ratio (not increment)
  % MDL(i).MES_D_inc = [ a b c d e f
    %                     ...        ];
  % Force variaiton ratio (not increment)
  % MDL(i).MES_F_inc = [ a b c d e f
    %                     ...        ];
end
```

```
% Check displacement and force limit
% At every steps, check if the displacement or force are approaching to the
% limitation of the equipments stroke or force capacity.
for i=1:Sys.Num_RF_Module
  MDL(i).CheckLimit  = 0;   % Module i
  % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement increment limit(not ratio)
  % MDL(i).TGT_D_inc = [ a b c d e f
    %                    ...        ];
    % Displacement limit
  % MDL(i).CAP_D_tot = [ a b c d e f
    %                    ...        ];
    % Force limit
  % MDL(i).CAP_F_tot = [ a b c d e f
    %                    ...        ];
    % Displacement tolerance (ratio)
  % MDL(i).TOL_D_inc = [ a b c d e f
    %                    ...        ];
end

% Loading and Boundary Condition Box (LBCB) case. If it's 1, the
% coordinate transformation matrix needs to be provided.
% This can be also used for any other actuator which has diffrence number of
% DOF coordinate with those of UI-SIMCOR

for i=1:Sys.Num_RF_Module
      MDL(i).LBCB = 0;
end

for i=1:Sys.Num_RF_Module
      MDL(i).LBCB_TransM = [];
end

% ____________________________________________________________________________
%
% Auxiliary module configuration
% ____________________________________________________________________________

% AUX(1)               = MDL_AUX;
% AUX(1).URL           = '127.0.0.1:12000';
% AUX(1).protocol      = 'labview1';
% AUX(1).name          = 'Camera';     % Module ID of this mdoule is 1
% AUX(1).Command       = {'displacement' 'z' 3500};
```

Variable Description

Sys.xi_1, Sys.Tn_1, Sys.xi_2, and Sys.Tn_2

Rayleigh damping with critical damping ratio of 3% in the 1st and 2nd modes is considered in this example.

Sys.Num_Node

There are 14 control points in this example as explained in 8.5.1, so Sys.Num_Node = 14.

Sys.Node_Mass

There are 14 control points, thus there are also 14 masses for each node only in x-direction. However, there are no mass in the one of control points of module 1 and control point of module 2 as shown in Figure 42. See the static module configuration file of each module for reference.

8.5.3 Static analysis module configuration

The configuration files for static analysis module are similar to those for MOST example. Thus further explanation is not given in this section. In the folder, *C:\SIMCOR\03_Examples\SAC,* there are sub folders containing the structural model file and module configuration files for FEDEAS Lab, ZEUS-NL, and ABAQUS. OpenSees model is not given for this example. There is one restraint in ABAQUS input file. It is option for imposing targeted displacement in the model. The restraint is that the order of the DOFs in the command (*boundary) should be the same as that of MDL.EFF_DOF{*i*}.
For example in SAC building,
From ABAQUS input file (Frame.inp)

….
*BOUNDARY
4,1,1,1.0
4,2,2,1.0
8,1,1,1.0
8,2,2,1.0
12,1,1,1.0
12,2,2,1.0
16,1,1,1.0
16,2,2,1.0
3,1,1,1.0
3,2,2,1.0
7,1,1,1.0
7,2,2,1.0
11,1,1,1.0
11,2,2,1.0
15,1,1,1.0
15,2,2,1.0
2,1,1,1.0
2,2,2,1.0
2,6,6,1.0
1,1,1,1.0
1,2,2,1.0
1,6,6,1.0
6,1,1,1.0
6,2,2,1.0
10,1,1,1.0
10,2,2,1.0
14,1,1,1.0
14,2,2,1.0
5,1,1,1.0
5,2,2,1.0
5,6,6,1.0
….

This order should be the same as in the AbaqusCFG.m file.

```
MDL.MDL_Node = [4 8 12 16 3 7 11 15 2 1 6 10 14 5];
MDL.EFF_DOF{1}  = [1 1 0 0 0 0];
MDL.EFF_DOF{2}  = [1 1 0 0 0 0];
MDL.EFF_DOF{3}  = [1 1 0 0 0 0];
MDL.EFF_DOF{4}  = [1 1 0 0 0 0];
MDL.EFF_DOF{5}  = [1 1 0 0 0 0];
MDL.EFF_DOF{6}  = [1 1 0 0 0 0];
MDL.EFF_DOF{7}  = [1 1 0 0 0 0];
MDL.EFF_DOF{8}  = [1 1 0 0 0 0];
MDL.EFF_DOF{9}  = [1 1 0 0 0 1];
MDL.EFF_DOF{10} = [1 1 0 0 0 1];
MDL.EFF_DOF{11} = [1 1 0 0 0 0];
MDL.EFF_DOF{12} = [1 1 0 0 0 0];
MDL.EFF_DOF{13} = [1 1 0 0 0 0];
MDL.EFF_DOF{14} = [1 1 0 0 0 1];
```

8.5.4 Running simulation

The running procedure of SAC example is very similar to that of MOST example, so further explanation is not give in this section.

8.5.5 Result and verification

In this example, Rayleigh damping is used as shown in Figure 43. The results of PSD test using UI-SIMCOR are very good correspondence with those of whole model run as shown in Figures 44 and 45.

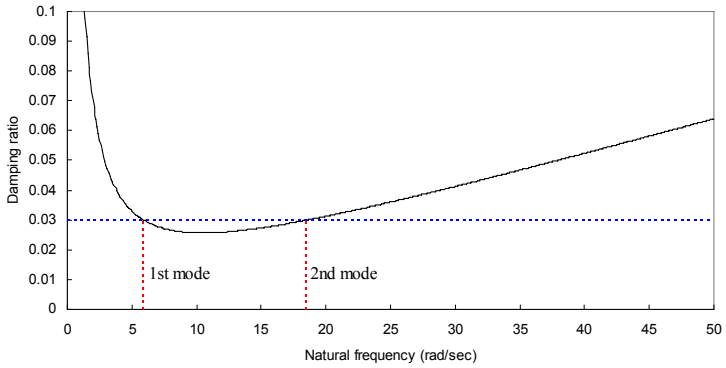


Figure 43 Rayleigh damping

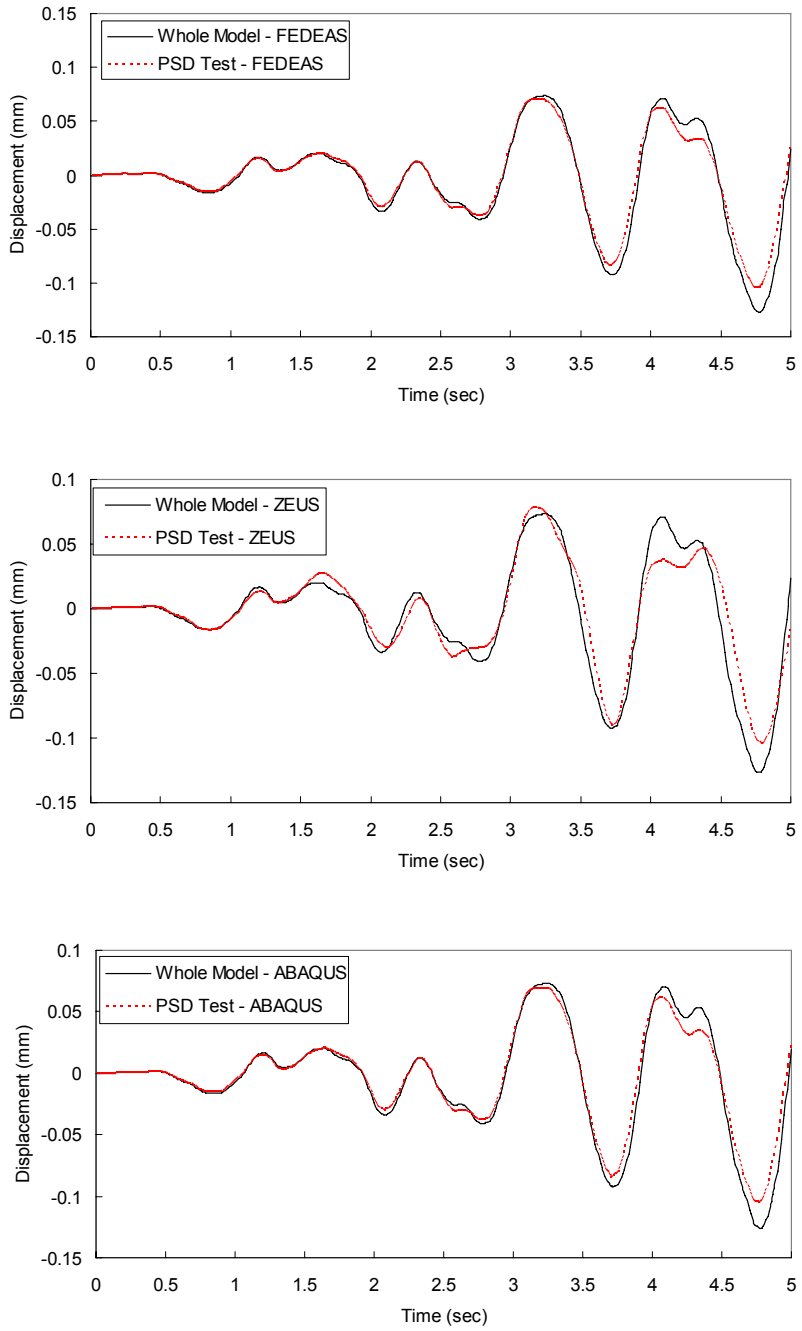


Figure 44 Pseudo dynamic test result – Horizontal displacement at top node of left column

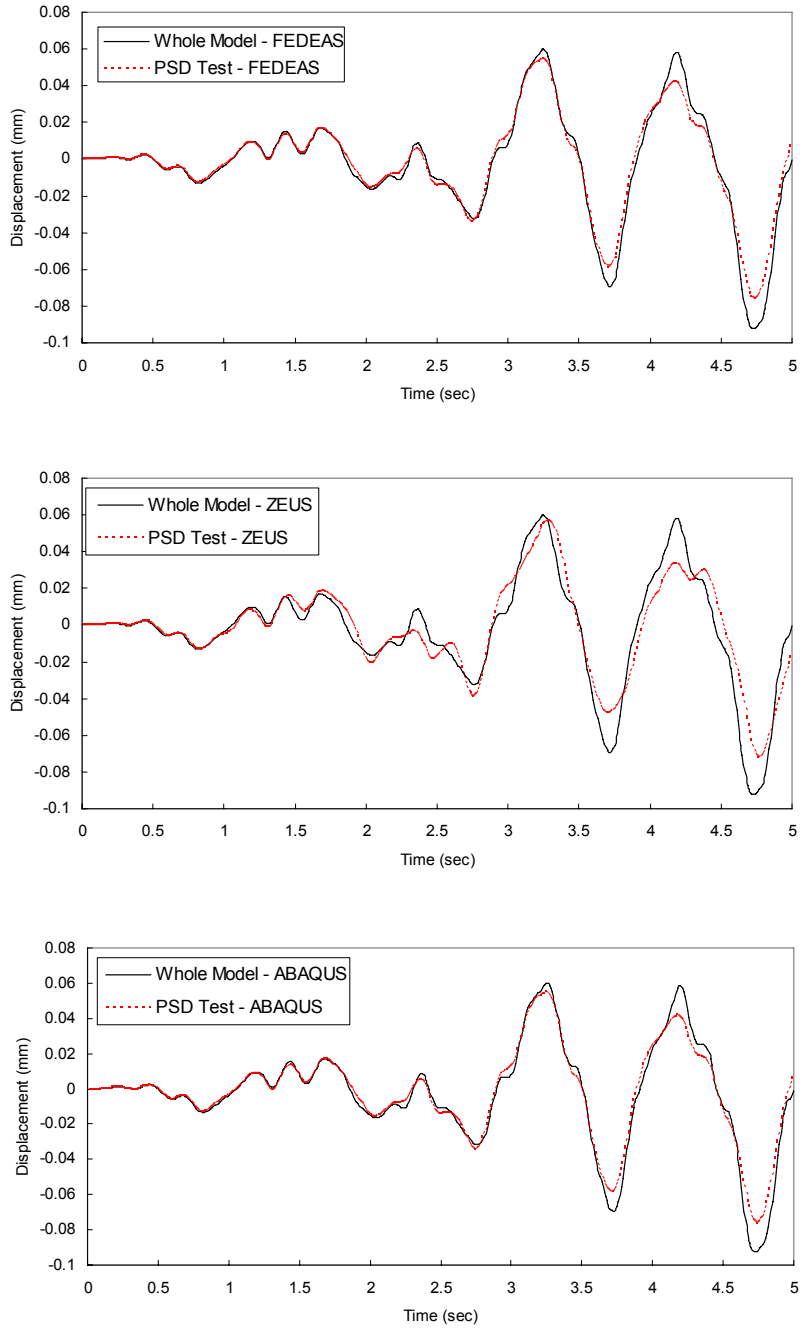


Figure 45 Pseudo dynamic test result – Horizontal displacement at the second floor of the third column

8.6 LBCB Example

The UI-SIMCOR calculates the target displacements related to effective DOFs and send these target displacements to actuators. However, experimental equipment can have different number of actuators with effective DOFs. For example, the LBCB in UIUC has 6 actuators, so 6 displacements should be sent to LBCB for experiment. For this purpose, two variables, i.e., MDL(*i*).LBCB and MDL(*i*).LBCB_TransM are used in the UI-SIMCOR. If the LBCB is used for experiment, the target displacements of all DOFs will be assigned as zero except effective DOFs. Furthermore the transformation matrix for LBCB needs to be defined and this transformation matrix is dependent on the location of LBCB plates. More details about LBCB can be found in *User's Manual for MUST-SIM Facility* (UIUC, 2005).

8.6.1 Structural configuration

The MOST example used in Section 8.4 is used for this LBCB example. The configuration of this example is exactly same with Section 8.4 except the left column as shown in Figure 46 and the left column represents the LBCB.

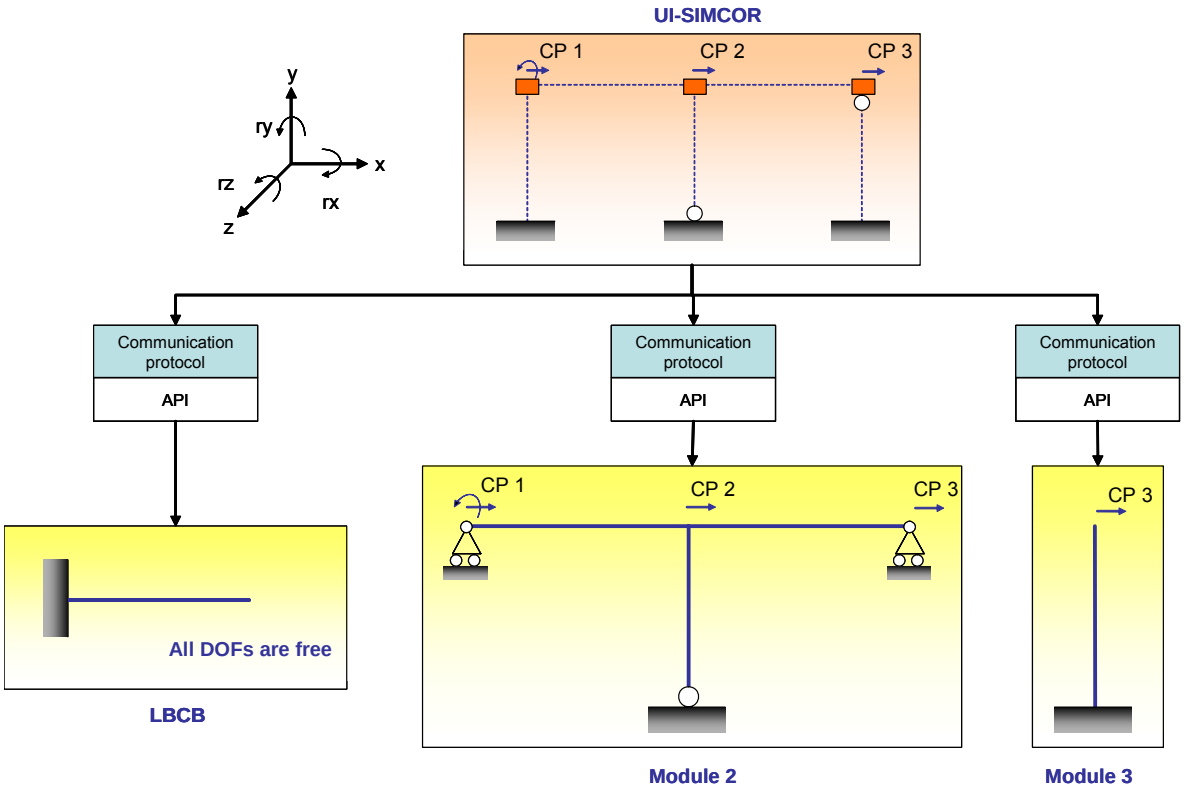


Figure 46 Simulation configuration for MOST_LBCB example

8.6.2 Simulation configuration file

The simulation configuration file of this example is exactly same with Section 8.4 except the LBCB variables.

C:\SIMCOR\03_Examples\MOST_LBCB\00_Coordinator\SimConfig.m

```
function [Sys, MDL, AUX] = SimConfig
MDL = MDL_RF; AUX = MDL_AUX;        % Type definition. Do not delete this line.
% ================================================================================
% Configuration parameters for MOST_LBCB example
%
% Unit: mm, N, sec
%
% by Oh-Sung Kwon, okwon2@uiuc.edu
% modified by Kyu-Sik Park, kspark@uiuc.edu
% Univ. of Illinois at Urbana Champaign
%
% Last updated on 2007-01-27 11:46AM
% ================================================================================

% _____________________________________________________________________________
%
% Common parameters
% _____________________________________________________________________________

% Ground acceleration file name with extension. The file should contains two
% columns for time and acceleration. The unit of acceleration should be
% consistent with the mass, time, and force. (i.e. mass*acc = force)
Sys.GM_Input = 'acc475C.dat';

% Ground acceleration scale factor. This factor will be multiplied to
% acceleration before starting simulation.
Sys.GM_SC = 9.81;

% Direction of ground acceleration. (x, y, or z)
Sys.GM_direction = 'x';

% Integration parameter related to the alpha-OS method.
% Alpha = (0 ~ 1/3). In most cases, SC.Alph = 0.05 worked.
Sys.Alph = 0.05;
Sys.Beta = 1/4*(1+Sys.Alph)^2;
Sys.Gamm = 1/2 + Sys.Alph;

% Evaluate Stiffness?
% Yes (1) to run stiffness evaluation test,
% No  (0) to read stiffness matrix from file. In this case, there should exist
%         stiffness matrices of individual module in the files MDL01_K.txt,
%         MDL02_K.txt, etc.
Sys.Eval_Stiffness = 0;

% Number of initial static loading steps. When there exist static constant
% loading,i.e. gravity forces, apply then in Zeus-NL or OpenSees as a
% incremental loading with 'n' steps. In this file, SimConfig.m, specify the
% number of static steps in the following variable.
Sys.Num_Static_Step = 0;

% Number of dynamic analysis steps
Sys.Num_Dynamic_Step = 500;
```

```
% Dynamic analysis time steps
Sys.dt = 0.01;

% Rayleigh damping, xi_1 and xi_2: Damping ratio, Tn_1, Tn_2: Target period
Sys.xi_1 = 0.00;
Sys.Tn_1 = 0.00;
Sys.xi_2 = 0.00;
Sys.Tn_2 = 0.00;

% Number of Stiffness test
% If stiffness is evaluated through experiment, the evaluation need to be done
% several times and the average of the results are used as the initial
% stiffness. This parameter is used when Sys.Eval_Stiffness = 1
Sys.Num_Test_Stiffness  = 1;

% Enable GUI for SimCor?
% Yes (1) enable the GUI for SimCor
% No  (0) disable the GUI for SimCor
%         Hybrid simulation will be run automatically.
%         Not recommended for the experiment.
Sys.EnableGUI       = 1;         % Use GUI for SimCor

% Number of restoring force modules.
Sys.Num_RF_Module     = 3;

% Number of auxilary modules.
Sys.Num_AUX_Module    = 0;

% Total number of effective nodes. Effective nodes are interface nodes between
% modules and nodes where lumped masses are defined.
Sys.Num_Node        = 3;

% Lumped mass assigned for each DOF for each node.
% Node number = x, y, z, rx, ry, rz directional mass
Sys.Node_Mass{1} = [2.54628081981000, 0, 0, 0, 0, 0];
Sys.Node_Mass{2} = [5.49705587697000, 0, 0, 0, 0, 0];
Sys.Node_Mass{3} = [2.54628081981000, 0, 0, 0, 0, 0];


% ____________________________________________________________________________
%
% Restoring force module configuration
% ____________________________________________________________________________

% Create objects of MDL_RF
MDL(1) = MDL_RF;
MDL(2) = MDL_RF;
MDL(3) = MDL_RF;

% Name of each module.
MDL(1).name = 'LeftCol_LBCB'; % Module ID of this module is 1
MDL(2).name = 'Middle'; % Module ID of this module is 2
MDL(3).name = 'RightCol'; % Module ID of this module is 3

% URL of each module
MDL(1).URL  = '127.0.0.1:11997';
MDL(2).URL  = '127.0.0.1:11998';
MDL(3).URL  = '127.0.0.1:11999';

% Communication protocol for each module.
%       NTCP         : communicate through NEESPOP server
%       TCPIP        : binary communication using TCPIP
%       LabView1     : ASCII communication with LabView plugin format
```

```
%                       (Propose-Query-Execute-Query)
%       LabView2     : same as LabView1 but Propose-Query
%       OpenFresco1D : OpenFresco, only 1 DOF is implemented now.
%       NHCP         : NHCP, linear 1 DOF simulation mode, Mini MOST 1 and 2 at
%                      UIUC or SDSC
MDL(1).protocol = 'LabView2';
MDL(2).protocol = 'LabView2';
MDL(3).protocol = 'LabView2';


% Module 1: Left column ---------------------------------------------------
MDL(1).node    = [1];           % Control point node number
MDL(1).EFF_DOF = [1 0 0 0 0 1]; % Effective DOF for CP 1


% Module 2: Middle column and beams ---------------------------------------
MDL(2).node    = [1 2 3];       % Control point node number
MDL(2).EFF_DOF = [1 0 0 0 0 1   % Effective DOF for CP 1
                  1 0 0 0 0 0    % Effective DOF for CP 2
                  1 0 0 0 0 0];  % Effective DOF for CP 3

% Module 3: Right column --------------------------------------------------
MDL(3).node    = [3];           % Control point node number
MDL(3).EFF_DOF = [1 0 0 0 0 0]; % Effective DOF for CP 3

% Dismplacement for preliminary test for each module
% Del_t: Translation, Del_r: Rotation in radian
MDL(1).DEL_t = 0.005;
MDL(2).DEL_t = 0.005;
MDL(3).DEL_t = 0.005;

MDL(1).DEL_r = 0.002;
MDL(2).DEL_r = 0.002;
MDL(3).DEL_r = 0.002;

% Enable GUI for each module?
% GUI for each module can only display the data.
% GUI for each module can not control the hybrid simulation.
% Yes (1) enable the GUI for each module
% No  (0) disable the GUI for each module
MDL(1).EnableGUI = 1;
MDL(2).EnableGUI = 1;
MDL(3).EnableGUI = 1;

% _____________________________________________________________________________
%
% Advanced modular parameters
% _____________________________________________________________________________
% These parameters need to be redefined for following situations.
%     (1) Different coordinate system between UI-SIMCOR and static module
%     (2) When scale factor needs to be applied either in experiment or
%         simulation
%     (3) To define force and displacement criteria (for tolerance and safety)
%     (4) To trigger camera modules or DAQ system
%     (5) When LBCB at UIUC is used for experiment
%     (6) When NHCP protocol is used
%
% URL of remote site and NHCP mode for NHCP
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).protocol), 'nhcp')
              MDL(i).remote_URL = '127.0.0.1:99999';
              MDL(i).NHCPMode = 'sim1d';
       end
```

```
end

% Stiffness for NHCP (Only valid if NHCPMode = 'Sim1D')
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).NHCPMode), 'sim1d')
              MDL(i).NHCPSimK = '1000';
       end
end

% Coordinate transformation. If it needs, the transformation matrix also
% needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).TransM = [];
end

% Scale factor for displacement, rotation, force, moment
% Experimental specimens are not always in full scale. Use this factors to
% apply scale factors.
% The displacement scale factors are multiplied before they are
% sent to module. Measured force and moments are divided with scale factors
% before used in the PSD algorithm.
for i=1:Sys.Num_RF_Module
       MDL(i).ScaleF = [1 1 1 1]; % Module i
end

% Relaxation check
% If this parameter is 1, UI_SimCor send commend to retrieve data and check
% relaxation just before the execution of proposed command. If it's 1, the
% checking criteria needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).CheckRelax  = 0;          % Module i
       % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement variation ratio (not increment)
  % MDL(i).MES_D_inc = [ a b c d e f
    %                     ...        ];
  % Force variaiton ratio (not increment)
  % MDL(i).MES_F_inc = [ a b c d e f
    %                     ...        ];
end

% Check displacement and force limit
% At every steps, check if the displacement or force are approaching to the
% limitation of the equipments stroke or force capacity.
for i=1:Sys.Num_RF_Module
  MDL(i).CheckLimit  = 0;   % Module i
  % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement increment limit(not ratio)
  % MDL(i).TGT_D_inc = [ a b c d e f
    %                     ...        ];
    % Displacement limit
  % MDL(i).CAP_D_tot = [ a b c d e f
    %                     ...        ];
    % Force limit
  % MDL(i).CAP_F_tot = [ a b c d e f
    %                     ...        ];
    % Displacement tolerance (ratio)
  % MDL(i).TOL_D_inc = [ a b c d e f
    %                     ...        ];
end
```

```
% Loading and Boundary Condition Box (LBCB) case. If it's 1, the
% coordinate transformation matrix needs to be provided.
% This can be also used for any other actuator which has diffrence number of
% DOF coordinate with those of UI-SIMCOR

MDL(1).LBCB = 1;
MDL(1).LBCB_TransM=[0 1 0 0 0 0;
                    -1 0 0 0 0 0;
                    0 0 1 0 0 0;
                    0 0 0 0 1 0;
                    0 0 0 -1 0 0;
                    0 0 0 0 0 1];

% ____________________________________________________________________________
%
% Advanced modular parameters
% ____________________________________________________________________________
% These parameters need to be redefined for following situations.
%     (1) Different coordinate system between UI-SIMCOR and static module
%     (2) When scale factor needs to be applied either in experiment or
%         simulation
%     (3) To define force and displacement criteria (for tolerance and safety)
%     (4) To trigger camera modules or DAQ system
%
% Coordinate transformation. If it needs, the transformation matrix also
% needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).TransM = [];
end

% Scale factor for displacement, rotation, force, moment
% Experimental specimens are not always in full scale. Use this factors to
% apply scale factors.
% The displacement scale factors are multiplied before they are
% sent to module. Measured force and moments are divided with scale factors
% before used in the PSD algorithm.
for i=1:Sys.Num_RF_Module
       MDL(i).ScaleF = [1 1 1 1]; % Module i
end

% Relaxation check
% If this parameter is 1, UI_SimCor send commend to retrieve data and check
% relaxation just before the execution of proposed command. If it's 1, the
% checking criteria needs to be provided.
for i=1:Sys.Num_RF_Module
       MDL(i).CheckRelax  = 0;          % Module i
       % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement variation ratio (not increment)
  % MDL(i).MES_D_inc = [ a b c d e f
    %                    ...        ];
  % Force variaiton ratio (not increment)
  % MDL(i).MES_F_inc = [ a b c d e f
    %                    ...        ];
end

% Check displacement and force limit
% At every steps, check if the displacement or force are approaching to the
% limitation of the equipments stroke or force capacity.
for i=1:Sys.Num_RF_Module
  MDL(i).CheckLimit  = 0;   % Module i
```

```
  % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement increment limit(not ratio)
  % MDL(i).TGT_D_inc = [ a b c d e f
    %                      ...        ];
    % Displacement limit
  % MDL(i).CAP_D_tot = [ a b c d e f
    %                      ...        ];
    % Force limit
  % MDL(i).CAP_F_tot = [ a b c d e f
    %                      ...        ];
    % Displacement tolerance (ratio)
  % MDL(i).TOL_D_inc = [ a b c d e f
    %                      ...        ];
end


% ____________________________________________________________________________
%
% Auxiliary module configuration
% ____________________________________________________________________________

% AUX(1)                = MDL_AUX;
% AUX(1).URL            = '127.0.0.1:12000';
% AUX(1).protocol       = 'labview1';
% AUX(1).name           = 'Camera';     % Module ID of this mdoule is 1
% AUX(1).Command        = {'displacement' 'z' 3500};
```

Variable Description

Most variables in SimConfig.m are explained in Section 8.4 for MOST example. In this section, variables that are related to LBCB are further explained.

MDL(*i*).LBCB

This variable defines the option of Loading and Boundary Condition Boxes (LBCB). UI-SIMCOR only calculates the target displacement of effective DOF. However, experimental equipment can have difference number of actuators with effective DOF. The in UIUC has 6 actuators, so 6 displacements should be sent to LBCB for experiment. If YES (1), the target displacements of all DOFs will be assigned as zero except effective DOF in UI-SIMCOR. If MDL(*i*).LBCB = 1, MDL(*i*).LBCB_TransM also needs to be defined.

MDL(*i*).LBCB_TransM

This variable defines the transformation matrix for LBCB. The coordinate system of LBCB is dependent on the location of plate. It is assumed that the x and y directions in UI-SIMCOR is transformed to y and x directions in LBCB, respectively. So, the transformation matrix for LBCB is

$$\text{LBCB\_TransM} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

8.6.3 Static analysis module configuration

The configuration files for static analysis module are similar to those for MOST example except the left column. Thus further explanation is not given in this section. In the folder, *C:\SIMCOR\03_Examples\MOST_LBCB,* there are sub folders containing the structural model file and module configuration files for ZEUS-NL and those of other static analysis modules are not given in this example.

There is one thing that needs attention. When ZEUS-NL is used as a static analysis module in which there are 6 DOFs for single control points, the static time history load should be defined in the order of 6 DOFs number. For instance, the left column of this example has one control point in which two DOFs are used. However, the LBCB has 6 DOFs so time history load should be defined in the order of control points and then 6 DOFs in ZEUS-NL input file,

```
time.history.loads
   nod.name     direction     type           crv.name     value
   n102         x             displacement   CV           1.
   n102         y             displacement   CV           1.
   n102         z             displacement   CV           1.
   n102         rx            displacement   CV           1.
   n102         ry            displacement   CV           1.
   n102         rz            displacement   CV           1.
```

8.6.4 Running simulation

The running procedure of this example is same with that of MOST example, so further explanation is not given in this section.

8.6.5 Result and verification

The simulation results show in Figure 47 and the “Normal” and “LBCB” mean the results from normal system and LBCB system, respectively. As shown in figure, the results of LBCB system are identical with those of normal system.

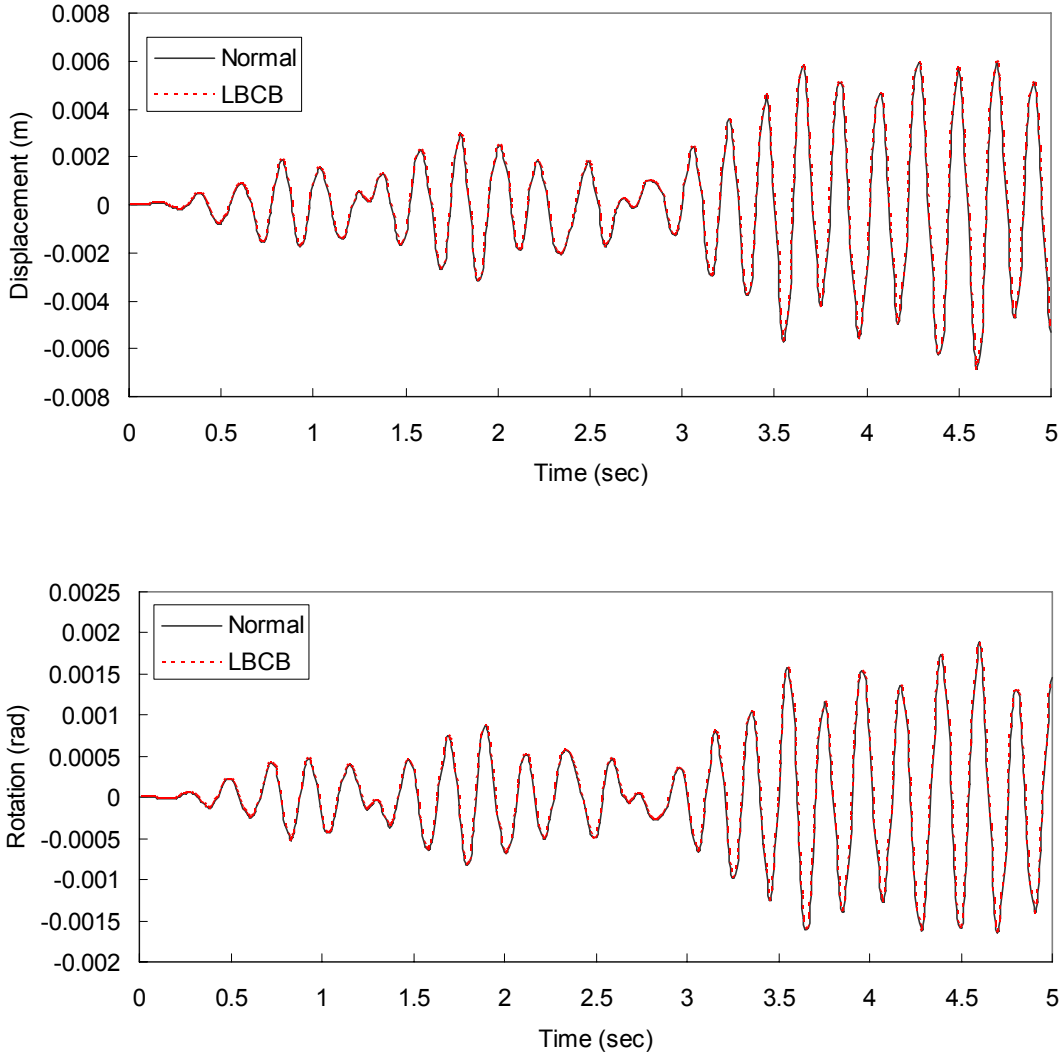


Figure 47 Pseudo dynamic test result – Responses at control point 1

8.7 Buckling Example using ABAQUS

In this section, inelastic post-buckling of cantilever column with unsymmetric open session and initial loading is briefly introduced using ABAQUS static analysis module. Use this example as a reference for solving buckling problem in ABAQUS.

The section used in this example is shown in Figure 48.

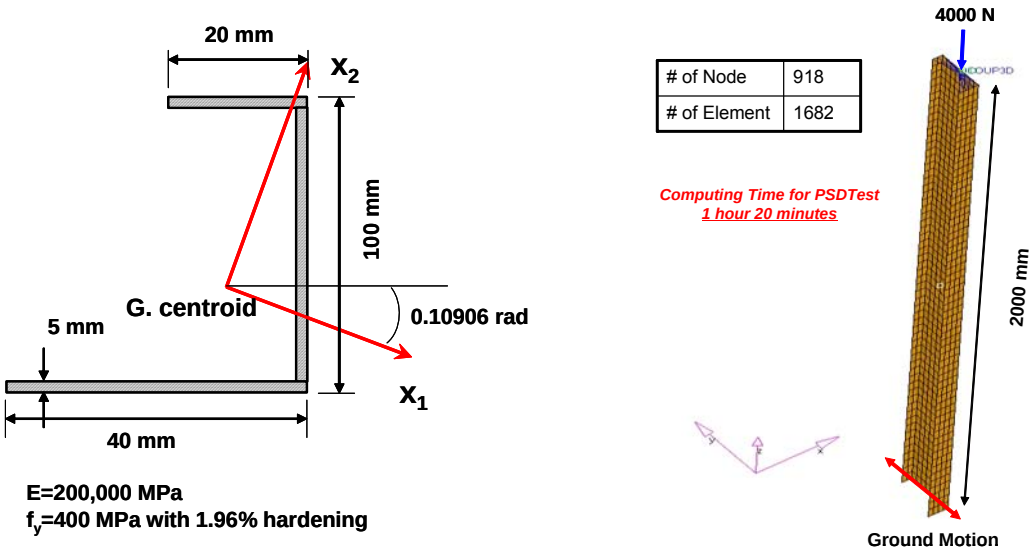


Figure 48 Buckling example

Figure 49 shows the effect of imperfection in dynamic responses. As shown in figure, effect of the geometric imperfection was negligible, so the imperfection was not considered in this example.

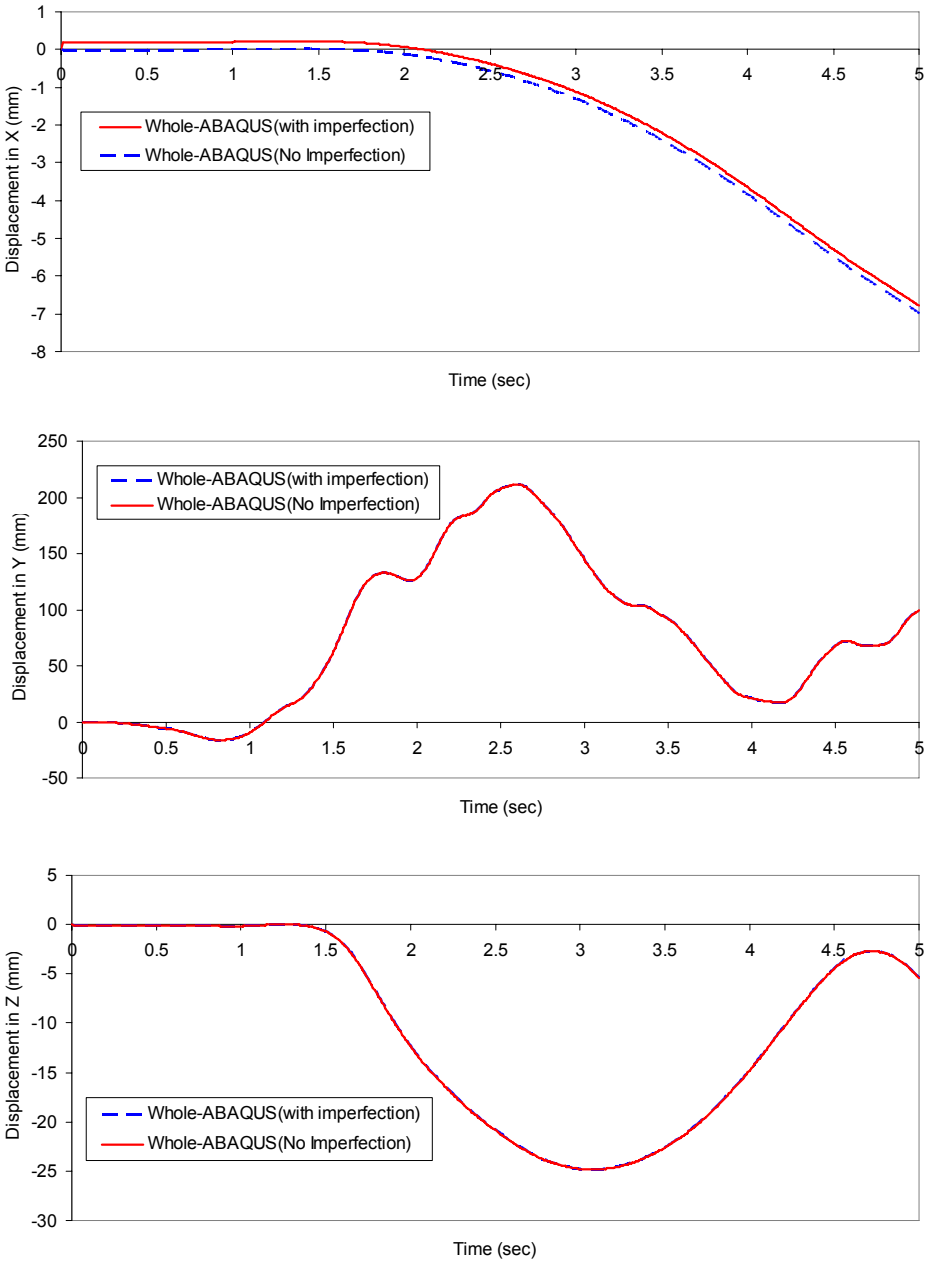


Figure 49 Comparison between w/ and w/o imperfection

Figure 50 shows the 3-DOF system for PSD test and Figures 51 ~ 53 are results of PSD test. As shown in figures, the PSD test results show good agreement with whole model.

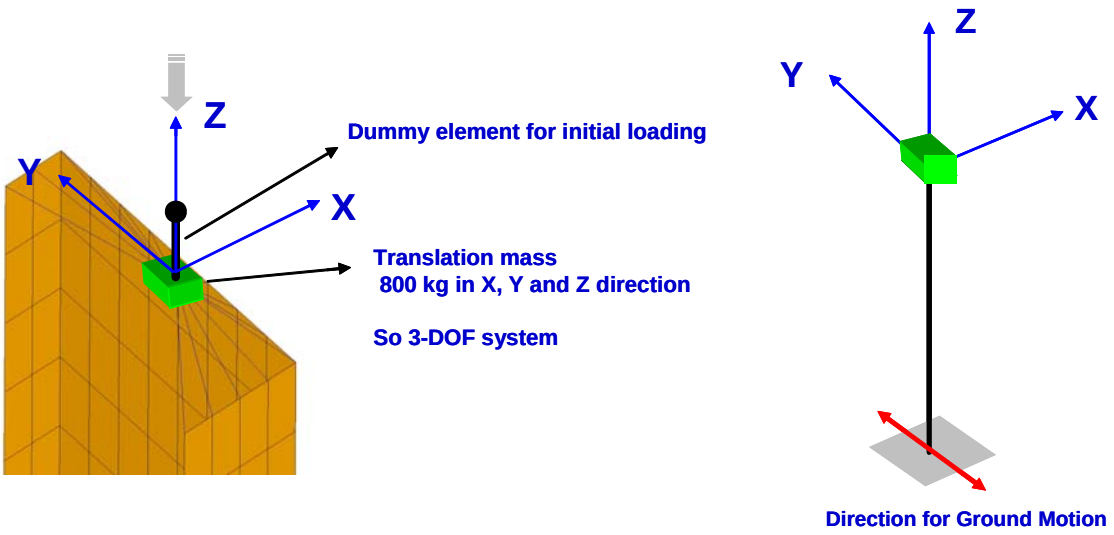


Figure 50 3-DOF system for PSD test

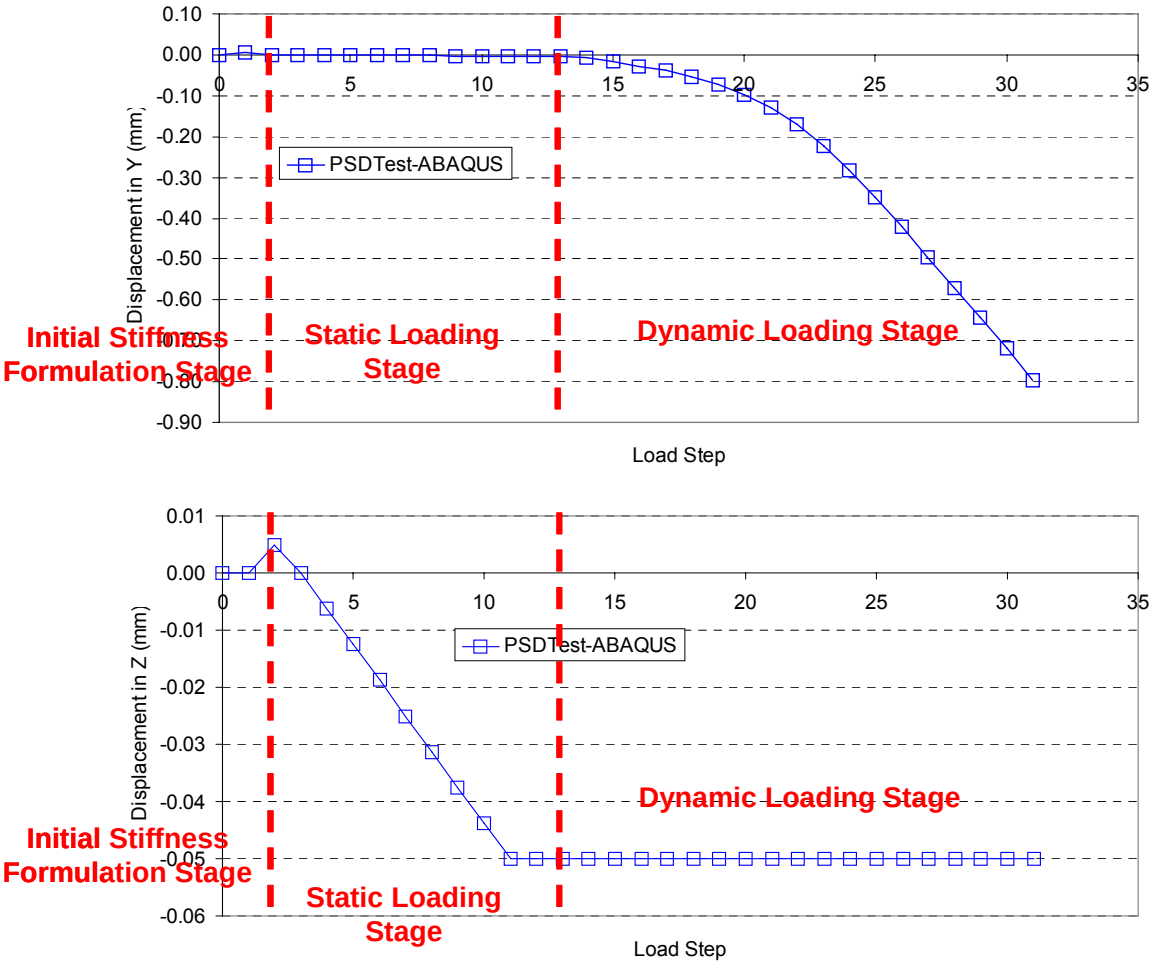


Figure 51 Displacement in Y and Z during PSD test

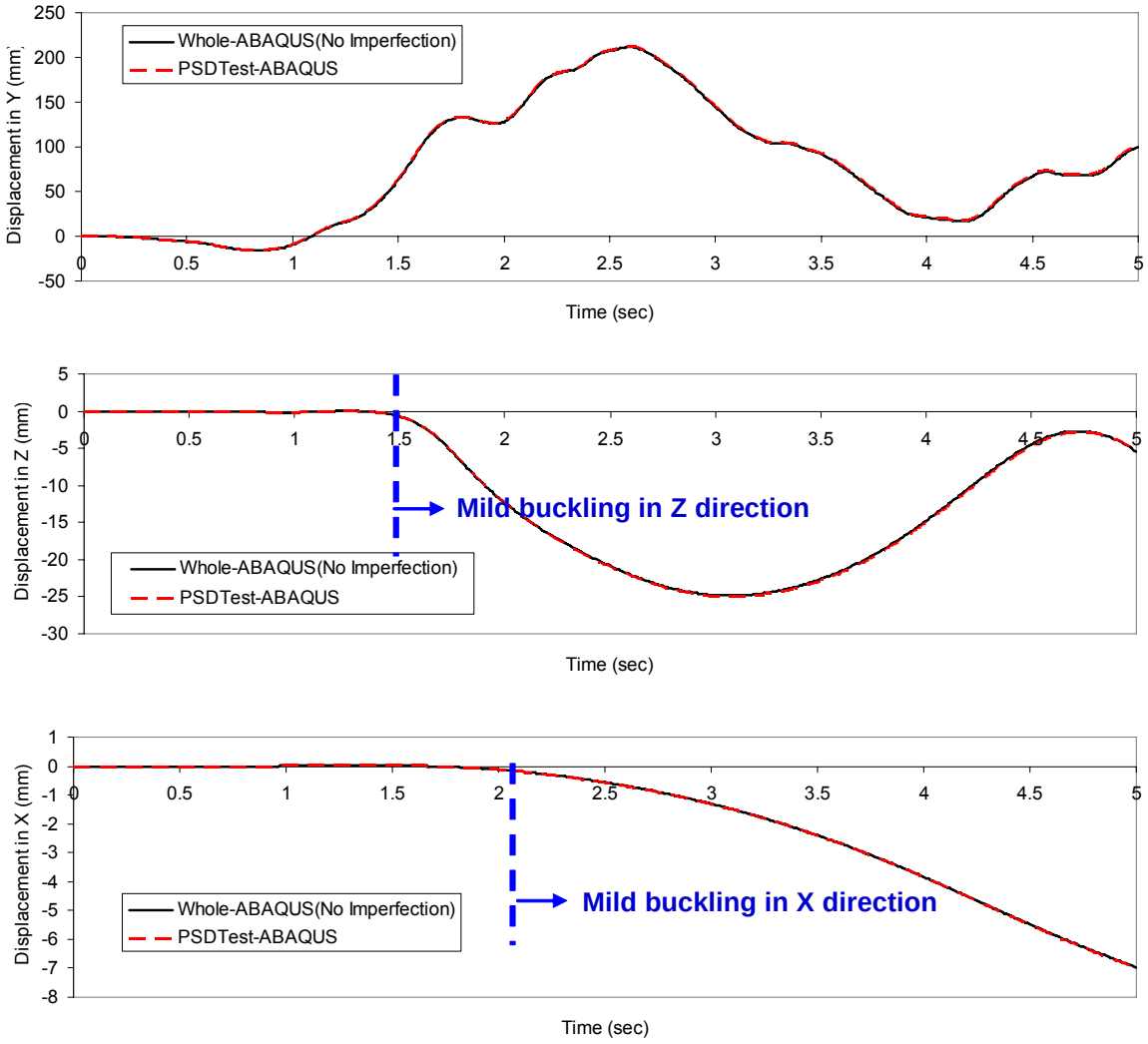


Figure 52 PSD test results – displacement

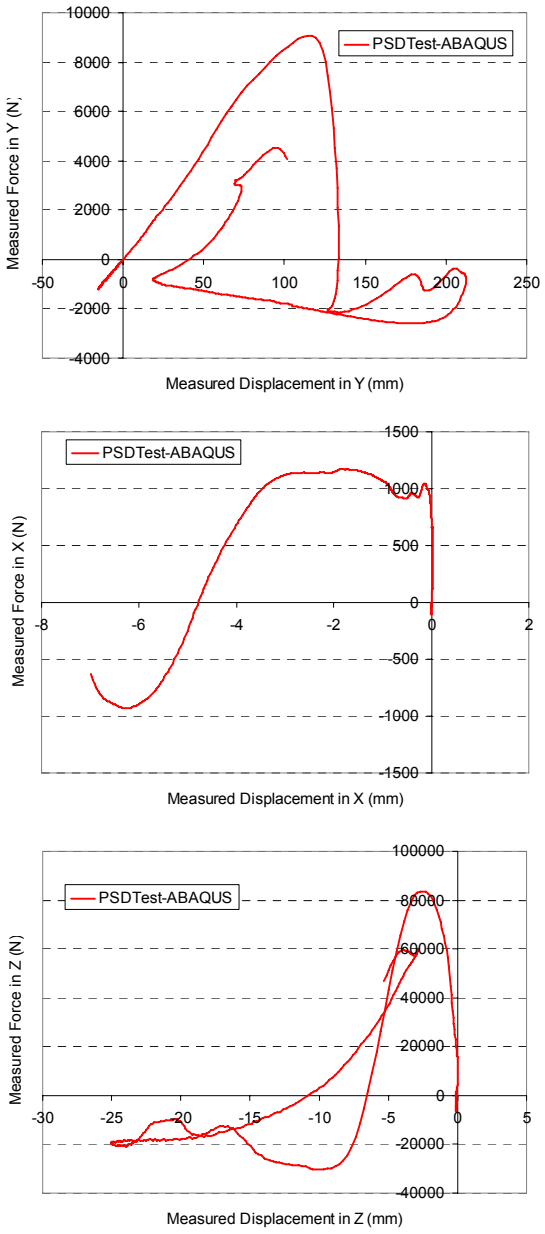


Figure 53 PSD test results – hysteresis loop

8.8 7-DOF Model using Five Protocols

8.8.1 Structural configuration

The main objective of this example is to verify the recently enhanced UI-SIMCOR including communication. This example structure is a bridge-like structure with five columns and six beams. This example has 7 control points and each control point only has one horizontal DOF. The material properties of this example are similar to those of MOST example in Section 8. 4. The hybrid simulation configuration is shown in Figure 54.

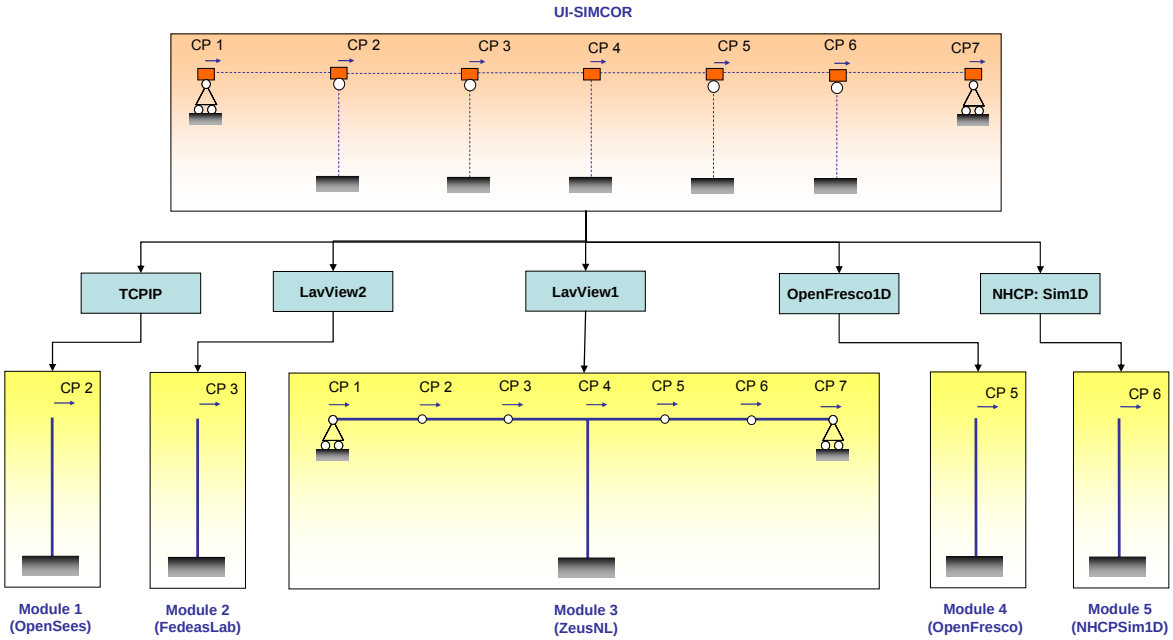


Figure 54 Hybrid simulation configuration

8.8.2 Simulation configuration file

Simulation configuration file contains all the information that is necessary for UI-SIMCOR for the multi-site simulation. Many parameters are already explained in the other examples.

C:\SIMCOR\03_Examples\6Beam5Col\00_Coordinator\SimConfig.m

```
function [Sys, MDL, AUX] = SimConfig
MDL = MDL_RF; AUX = MDL_AUX;        % Type definition. Do not delete this line.
% ================================================================================
% Configuration parameters for 6Beam5Col Examples to test five protocols,
% i.e., TCPIP, LabView1, LabView2, OpenFresco1D, and NHCP
%
% Unit: m, kN, sec
%
% by Kyu-Sik Park, kspark@uiuc.edu
```

```
% Univ. of Illinois at Urbana Champaign
%
% Last updated on 2007-01-27 10:56AM
% ========================================================================

% ____________________________________________________________________________
%
% Common parameters
% ____________________________________________________________________________

% Ground acceleration file name with extension. The file should contains two
% columns for time and acceleration. The unit of acceleration should be
% consistent with the mass, time, and force. (i.e. mass*acc = force)
Sys.GM_Input = 'acc475C.dat';

% Ground acceleration scale factor. This factor will be multiplied to
% acceleration before starting simulation.
Sys.GM_SC = 9.81;

% Direction of ground acceleration. (x, y, or z)
Sys.GM_direction = 'x';

% Integration parameter related to the alpha-OS method.
% Alpha = (0 ~ 1/3). In most cases, SC.Alph = 0.05 worked.
Sys.Alph = 0.2;
Sys.Beta = 1/4*(1+Sys.Alph)^2;
Sys.Gamm = 1/2 + Sys.Alph;

% Evaluate Stiffness?
% Yes (1) to run stiffness evaluation test,
% No  (0) to read stiffness matrix from file. In this case, there should exist
%         stiffness matrices of individual module in the files MDL01_K.txt,
%         MDL02_K.txt, etc.
Sys.Eval_Stiffness = 1;

% Number of initial static loading steps. When there exist static constant
% loading,i.e. gravity forces, apply then in Zeus-NL or OpenSees as a
% incremental loading with 'n' steps. In this file, SimConfig.m, specify the
% number of static steps in the following variable.
Sys.Num_Static_Step = 0;

% Number of dynamic analysis steps
Sys.Num_Dynamic_Step = 500;

% Dynamic analysis time steps
Sys.dt = 0.01;

% Rayleigh damping, xi_1 and xi_2: Damping ratio, Tn_1, Tn_2: Target period
Sys.xi_1 = 0.00;
Sys.Tn_1 = 0.00;
Sys.xi_2 = 0.00;
Sys.Tn_2 = 0.00;

% Number of Stiffness test
% If stiffness is evaluated through experiment, the evaluation need to be done
% several times and the average of the results are used as the initial
% stiffness. This parameter is used when Sys.Eval_Stiffness = 1
Sys.Num_Test_Stiffness  = 1;

% Enable GUI for SimCor?
% Yes (1) enable the GUI for SimCor
% No  (0) disable the GUI for SimCor
%         Hybrid simulation will be run automatically.
```

```
%         Not recommended for the experiment.
Sys.EnableGUI       = 1;         % Use GUI for SimCor

% Number of restoring force modules.
Sys.Num_RF_Module     = 5;

% Number of auxilary modules.
Sys.Num_AUX_Module    = 0;

% Total number of effective nodes. Effective nodes are interface nodes between
% modules and nodes where lumped masses are defined.
Sys.Num_Node        = 7;

% Lumped mass assigned for each DOF for each node.
% Node number = x, y, z, rx, ry, rz directional mass
Sys.Node_Mass{1} = [2.54628, 0, 0, 0, 0, 0];
Sys.Node_Mass{2} = [5.49706, 0, 0, 0, 0, 0];
Sys.Node_Mass{3} = [5.49706, 0, 0, 0, 0, 0];
Sys.Node_Mass{4} = [5.49706, 0, 0, 0, 0, 0];
Sys.Node_Mass{5} = [5.49706, 0, 0, 0, 0, 0];
Sys.Node_Mass{6} = [5.49706, 0, 0, 0, 0, 0];
Sys.Node_Mass{7} = [2.54628, 0, 0, 0, 0, 0];

% ____________________________________________________________________________
%
% Restoring force module configuration
% ____________________________________________________________________________

% Create objects of MDL_RF
MDL(1) = MDL_RF;
MDL(2) = MDL_RF;
MDL(3) = MDL_RF;
MDL(4) = MDL_RF;
MDL(5) = MDL_RF;

% Name of each module.
% Simulation witout scale factor
MDL(1).name = 'OS_TCPIP';  % Module ID of this module is 1
MDL(2).name = 'FL_LV2';    % Module ID of this module is 2
MDL(3).name = 'ZEUS_LV1';  % Module ID of this module is 3
MDL(4).name = 'OF_OF1D';    % Module ID of this module is 4
MDL(5).name = 'Sim1D_NHCP'; % Module ID of this module is 5

% URL of each module
MDL(1).URL  = '127.0.0.1:11991';
MDL(2).URL  = '127.0.0.1:11992';
MDL(3).URL  = '127.0.0.1:11993';
MDL(4).URL  = '127.0.0.1:11994';
MDL(5).URL  = '127.0.0.1:11995';

% Communication protocol for each module.
%       NTCP         : communicate through NEESPOP server
%       TCPIP        : binary communication using TCPIP
%       LabView1     : ASCII communication with LabView plugin format
%                      (Propose-Query-Execute-Query)
%       LabView2     : same as LabView1 but Propose-Query
%       OpenFresco1D : OpenFresco, only 1 DOF is implemented now.
%       NHCP         : NHCP, linear 1 DOF simulation mode, Mini MOST 1 and 2 at
%                      UIUC or SDSC
MDL(1).protocol = 'TCPIP';
MDL(2).protocol = 'LabView2';
MDL(3).protocol = 'LabView1';
MDL(4).protocol = 'OpenFresco1D';
```

```
MDL(5).protocol = 'NHCP';

% Module 1: OpenSees with TCPIP ------------------------------------------------
MDL(1).node    = [2];           % Control point node number
MDL(1).EFF_DOF = [1 0 0 0 0 0]; % Effective DOF for CP 2

% Module 2: Fedeas Lab with LabView2 -------------------------------------------
MDL(2).node    = [3];           % Control point node number
MDL(2).EFF_DOF = [1 0 0 0 0 0]; % Effective DOF for CP 3

% Module 3: ZeusNL with LabView2 -----------------------------------------------
MDL(3).node    = [1 2 3 4 5 6 7];% Control point node number
MDL(3).EFF_DOF = [1 0 0 0 0 0    % Effective DOF for CP 1
                  1 0 0 0 0 0    % Effective DOF for CP 2
                  1 0 0 0 0 0    % Effective DOF for CP 3
                  1 0 0 0 0 0    % Effective DOF for CP 4
                  1 0 0 0 0 0    % Effective DOF for CP 5
                  1 0 0 0 0 0    % Effective DOF for CP 6
                  1 0 0 0 0 0];  % Effective DOF for CP 7

% Module 4: OpenFresco with OpenFresco1D ---------------------------------------
MDL(4).node    = [5];           % Control point node number
MDL(4).EFF_DOF = [1 0 0 0 0 0]; % Effective DOF for CP 5

% Module 5: NHCPSim1D with NHCP ------------------------------------------------
MDL(5).node    = [6];           % Control point node number
MDL(5).EFF_DOF = [1 0 0 0 0 0]; % Effective DOF for CP 6

% Dismplacement for preliminary test for each module
% Del_t: Translation, Del_r: Rotation in radian
MDL(1).DEL_t = 0.0005;
MDL(2).DEL_t = 0.0005;
MDL(3).DEL_t = 0.0005;
MDL(4).DEL_t = 0.0005;
MDL(5).DEL_t = 0.0005;

MDL(1).DEL_r = 0.0002;
MDL(2).DEL_r = 0.0002;
MDL(3).DEL_r = 0.0002;
MDL(4).DEL_r = 0.0002;
MDL(5).DEL_r = 0.0002;

% Enable GUI for each module?
% GUI for each module can only display the data.
% GUI for each module can not control the hybrid simulation.
% Yes (1) enable the GUI for each module
% No  (0) disable the GUI for each module
MDL(1).EnableGUI = 1;
MDL(2).EnableGUI = 1;
MDL(3).EnableGUI = 1;
MDL(4).EnableGUI = 1;
MDL(5).EnableGUI = 1;

% ____________________________________________________________________________
%
% Advanced modular parameters
% ____________________________________________________________________________
% These parameters need to be redefined for following situations.
%     (1) Different coordinate system between UI-SIMCOR and static module
%     (2) When scale factor needs to be applied either in experiment or
%         simulation
%     (3) To define force and displacement criteria (for tolerance and safety)
%     (4) To trigger camera modules or DAQ system
```

```
%     (5) When LBCB at UIUC is used for experiment
%     (6) When NHCP protocol is used
%
% URL of remote site and NHCP mode for NHCP
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).protocol), 'nhcp')
              MDL(i).remote_URL = '127.0.0.1:99999';
              MDL(i).NHCPMode = 'sim1d';
       end
end

% Stiffness for NHCP (Only valid if NHCPMode = 'Sim1D')
for i=1:Sys.Num_RF_Module
       if strcmp(lower(MDL(i).NHCPMode), 'sim1d')
              MDL(i).NHCPSimK = '1.5842359e+003';
       end
end

% Coordinate transformation. If it needs, the transformation matrix also
% needs to be provided.
for i=1:Sys.Num_RF_Module
  MDL(i).TransM = [];
end

% Scale factor for displacement, rotation, force, moment
% Experimental specimens are not always in full scale. Use this factors to
% apply scale factors.
% The displacement scale factors are multiplied before they are
% sent to module. Measured force and moments are divided with scale factors
% before used in the PSD algorithm.
for i=1:Sys.Num_RF_Module
  MDL(i).ScaleF = [1 1 1 1];  % Module i
end

% Relaxation check
% If this parameter is 1, UI_SimCor send commend to retrieve data and check
% relaxation just before the execution of proposed command. If it's 1, the
% checking criteria needs to be provided.
for i=1:Sys.Num_RF_Module
  MDL(i).CheckRelax  = 0;   % Module i
  % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement variation ratio (not increment)
  % MDL(i).MES_D_inc = [ a b c d e f
    %                    ...       ];
  % Force variaiton ratio (not increment)
  % MDL(i).MES_F_inc = [ a b c d e f
    %                    ...       ];
end

% Check displacement and force limit
% At every steps, check if the displacement or force are approaching to the
% limitation of the equipments stroke or force capacity.
for i=1:Sys.Num_RF_Module
  MDL(i).CheckLimit  = 0;   % Module i
  % if MDL(i).CheckLimit=1, define following variables.
  % Variable size should be (number of control nodes)* 6 array
  %
  % Displacement increment limit(not ratio)
  % MDL(i).TGT_D_inc = [ a b c d e f
    %                    ...       ];
    % Displacement limit
```

```
  % MDL(i).CAP_D_tot = [ a b c d e f
    %                    ...        ];
    % Force limit
  % MDL(i).CAP_F_tot = [ a b c d e f
    %                    ...        ];
    % Displacement tolerance (ratio)
  % MDL(i).TOL_D_inc = [ a b c d e f
    %                    ...        ];
end

% Loading and Boundary Condition Box (LBCB) case. If it's 1, the
% coordinate transformation matrix needs to be provided.
% This can be also used for any other actuator which has diffrence number of
% DOF coordinate with those of UI-SIMCOR

for i=1:Sys.Num_RF_Module
  MDL(i).LBCB = 0;
end

for i=1:Sys.Num_RF_Module
  MDL(i).LBCB_TransM = [];
end
% ____________________________________________________________________________
%
% Auxiliary module configuration
% ____________________________________________________________________________

% AUX(1)                = MDL_AUX;
% AUX(1).URL            = '127.0.0.1:12000';
% AUX(1).protocol       = 'labview1';
% AUX(1).name           = 'Camera';     % Module ID of this mdoule is 1
% AUX(1).Command        = {'displacement' 'z' 3500};
```

8.8.3 Running simulation

1. Module 1 – OpenSees with TCP/IP protocol
    a. Start NEES-SAM by double clicking NEESSAM_TCPIP.exe.
    b. Select the configuration file from the folder where configuration file and model file exist.
    c. Check the open port and status.
2. Module 2 – FEDEAS Lab with LabVIEW2 protocol
    a. Start a MATLAB
    b. Change current directory to the folder where FedeasCFG.m and the model file, MDL02.m, exist.
    c. Run FEDEAS Lab by inputting following command **NEES_FL_LabView2 [enter]**.
3. Module 3- ZEUS-NL with LabVIEW1 protocol
    a. Start NEES-SAM by double clicking NEESSAM_TCPIP.exe.
    b. Select the configuration file from the folder where configuration file and model file exist.
    c. Check the open port and status.
4. Module 4 – OpenFresco with OpenFresco1D protocol
    a. Start WINDOW DOS command window and change current directory to the folder where the model file, MDL04.tcl, exists.

   b. Run OpenFresco by inputting **OpenFresco [enter]**.
   c. Load model file by inputting **source MDL04.tcl [enter]**.
5. Module 5 – NHCPSim1D with NHCP protocol
   a. Start WINDOW DOS command window and change current directory to the folder where the ncs.exe exists.
   b. Run NCS by inputting **ncs portnumber [enter]** where portnumber is defined in the SimConfig.m file (MDL(i).URL).
   c. Start another WINDOW DOS command window and change current directory to the folder where the simserver.exe exists.
   d. Run SimServer by inputting **simserver portnumber [enter]** where portnumber is defined in the SimConfig.m file (MDL(i).remote_URL).

8.8.4 Result and verification

The results of PSD test using UI-SIMCOR are very good correspondence with those of whole model run as shown in Figure 55.

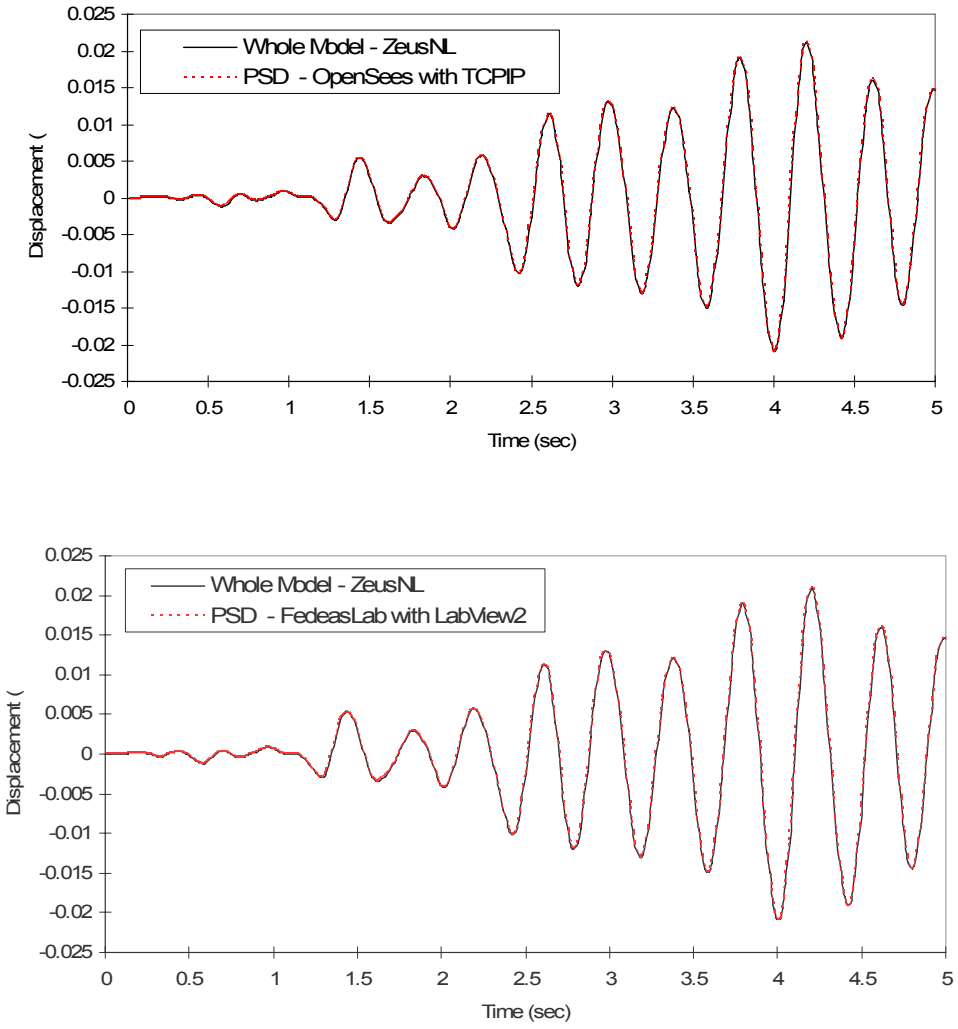


Figure 55 Pseudo dynamic test result – Horizontal displacement

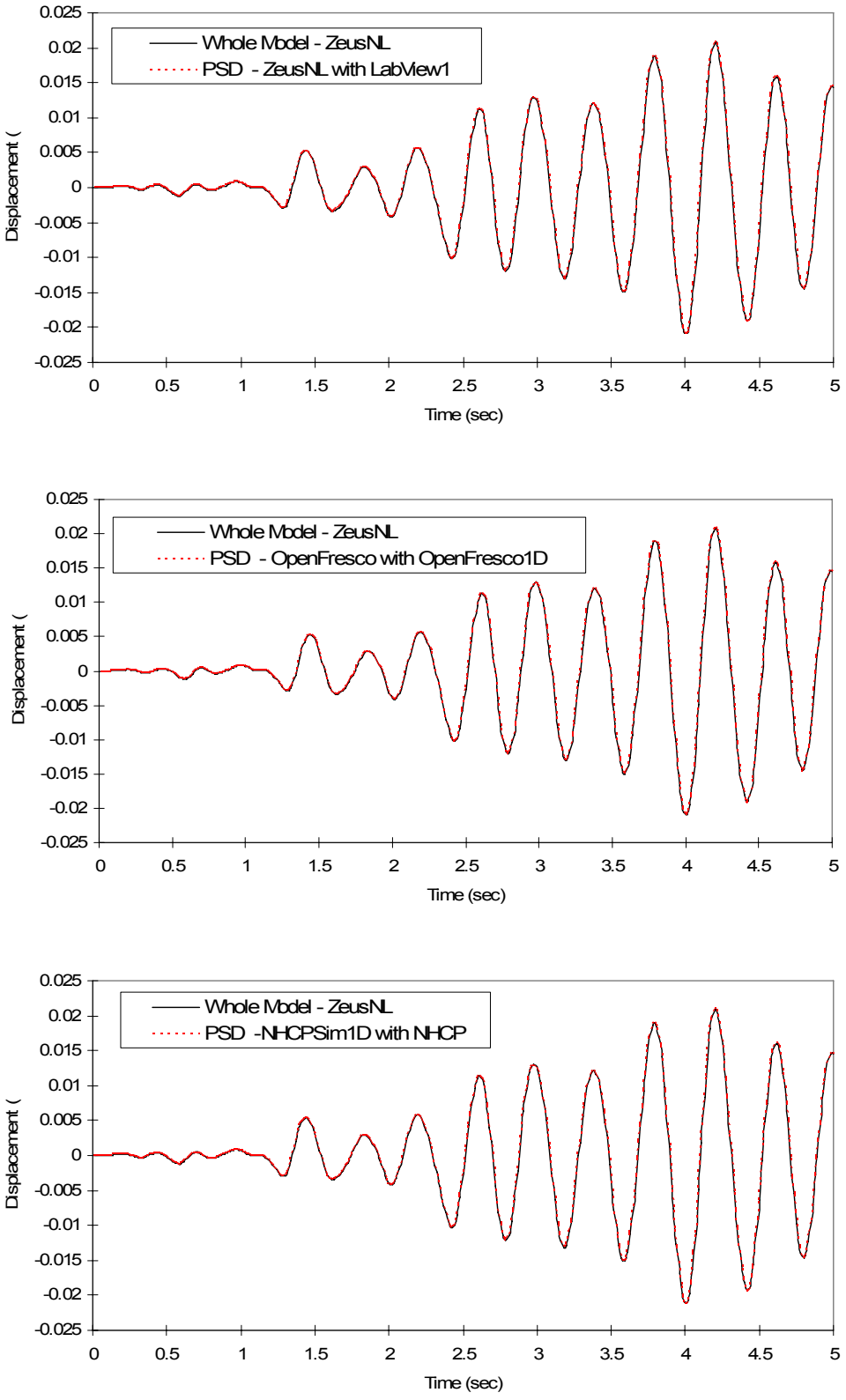


Figure 55 Pseudo dynamic test result

9. Specific Experimental Issues

Every experimental site may have their own configuration of the actuators, measurement systems, and data formats. As a result, the global data format that is sent through communication protocol may not directly adaptable to each experimental site. In these specific situations, it is necessary to develop an API which acts as an adapter between experimental sites and UI-SIMCOR (strictly speaking, communication protocol).

In this section various application examples using UI-SIMCOR are explained. Various experiments including one-site, two-site, and three-site hybrid test using UI-SIMCOR with various specimen were conducted at UIUC, UCB, and SDSC to verify and demonstrate the efficacy of UI-SIMCOR.

9.1 One-site Experiment with μNEES at UCB

To verify UI-SIMCOR with other experimental site, one-site experiment with μNEES facilities at UCB was conducted during August 9, 2006 ~ August 16, 2006. This test was conducted as preliminary test for two-site hybrid test between UIUC and UCB. The two-site hybrid test will be explained in the next section.

9.1.1 Experiment setup: μNEES laboratory

The μNEES facility at UCB was used for the hybrid test. The overview of the small scale cantilever specimen setup is shown in Figure 56. This setup allows one or two columns to be tested. They can be tested using the same control system or two different control systems. There are two identical setups, each consisting of a cantilevered beam-column element positioned in a self-equilibrating reaction frame. Each beam-column element is attached to an actuator on one end. At the other end, a special clevis attaches the cantilever to the supporting frame. The clevis allows free rotation, but no translation or axial movement. To provide bending stiffness and strength at the clevis, specially machined coupons are bolted to the clevises' end plates. By selecting the number of coupons, their diameter and slenderness, and the manner by which the coupons are bolted to the clevises, a wide variety of hysteretic loop characteristics can be obtained.

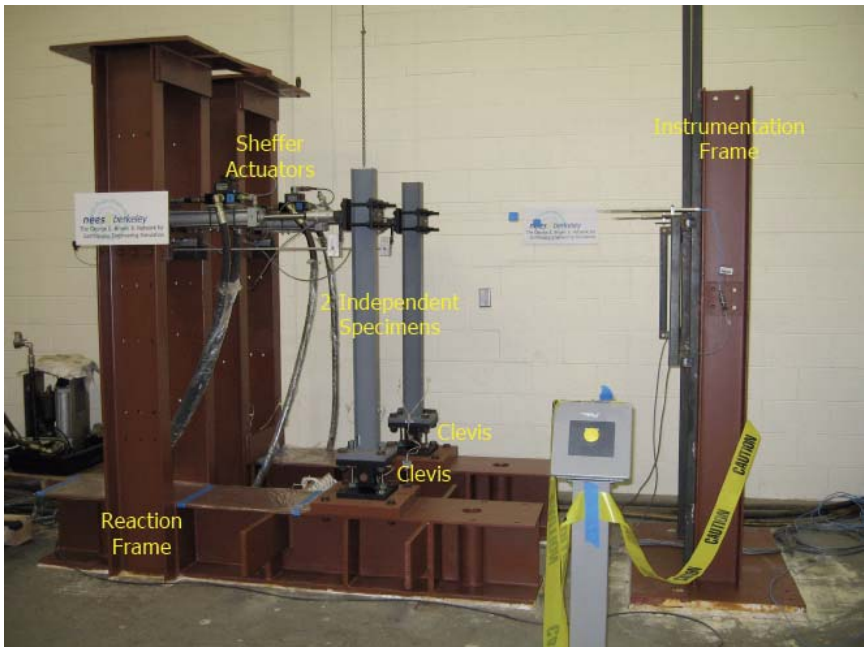


Figure 56 Overview of μNEES specimen (Schellenberg, et. al., 2006)

The experiment setup in the μNEES laboratory uses two actuators manufactured by Sheffer (2.5HHTF15). The brief description of 2.5HHTF15 actuator is shown in Table 1.

Table 1. 2.5HHTF15 actuator

Load capacity	±50 kN (±12 kips)
Stroke	375 mm (15 in)
Velocity	625 mm/sec (25 in/sec)

The controllers provided for the μNEES facility perform the real-time, or near real-time digital control of the hydraulic system for the pseudo-dynamic testing. The controllers support a local testing with real specimens only a hybrid simulation with virtual specimens (computer models) and real specimens coupled in a complex system through geographically distributed network. There are two separate digital control platforms provided by MTS. The first is the MTS 493 Real-Time Controller (supporting software called Structural Test System: STS) that performs the real time, or near real time pseudo-dynamic structural testing capabilities. The second digital control platform is the MTS FlexTest GT Controller that provides a highly flexible and user configurable control environment to support more conventional structural testing applications. In addition, ATS Control and DAQ cart with dSpace DS1104 real-time environment are used for data acquisition system.

During this preliminary hybrid test, only one actuator and one specimen were used.

More detailed information and documents about μNEES laboratory can be found in the following nees@berkeley link.

http://nees.berkeley.edu/

9.1.2 Customization of μNEES facility for UI-SIMCOR

Following aspects were considered during the experiment at UCB to communicate with UI-SIMCOR. This is the most important and possible difficult step depending on the interface that people use for experiment. Any program language which can impose displacement and collect measured displacement and force from experiment can be used. If they use common protocol such as LabVIEW plugin via NTCP, there is no need of customization. Otherwise, the experiment site should provide a method of communication. In UCB, Tony and Andreas provides us a MATLAB function which runs experiment and returns measured data.

It is recommended for user to keep in mind the communication procedure of the experiment control program with UI-SIMCOR and followings.

- Figure out how to send the displacement command and get the feedback data from experiment. UCB sites uses Shared Common RAM Network (SCRAMNET) and xPC Real-time target to impose data and read feedback. A MATLAB function is provided by Tony and Andreas for this purpose. The functions are used in the scripts within the folder C:\SIMCOR\04_API\01_UCB.
- Customize an interface program which can receive and send data through TCP/IP network. For UCB site, MATLAB scripts were developed which can receive data from UI-SIMCOR through network, call the provided MATLAB function, and send the feedback to UI-SIMCOR through network.
- Set the IP address and port number.

Furthermore, followings should be confirmed for xPC Real-time target.

- The application name for xPC Real-time target of the experiment is HybridControllerPoly3_1Act.
- The function which uses for initialize the xPC Real-time target, execute experiment (propose the target displacement), and acquire the measured data is HybridControlxPCtarget.
- The directory for initialization of xPC Real-time target is D:\OpenSees\PredictorCorrector\RTActualTestModels\c&mCode-xPCTarget-STS.

9.1.3 Pushover test

Before the hybrid test, the pushover test was conducted to calculate scale factor in UI-SIMCOR and to make an analytical model for comparison after test. The specimen provided by UCB is shown in Figure 57.

Figure 57 Specimen at UCB

Running procedure

The procedure in this section is for the UCB site. The procedure may vary with different experimental configurations. Figure 58 shows the configuration of hybrid simulation framework in UCB. The most important customization was writing API for UCB site which acts key role for communication between UI-SIMCOR and experimental site.

Before starting the experiment, make sure followings.

- Restart the PC for xPC Real-time target for every new hybrid test: After upgrading MATLAB from 7.0 to 7.1, the PC needed to be restarted. It seems like a version compatibility problem of MATLAB.
- Set the displacement limit of the specimen for safety.
- Zero the initial displacement and initial force of controller, both of them if possible.

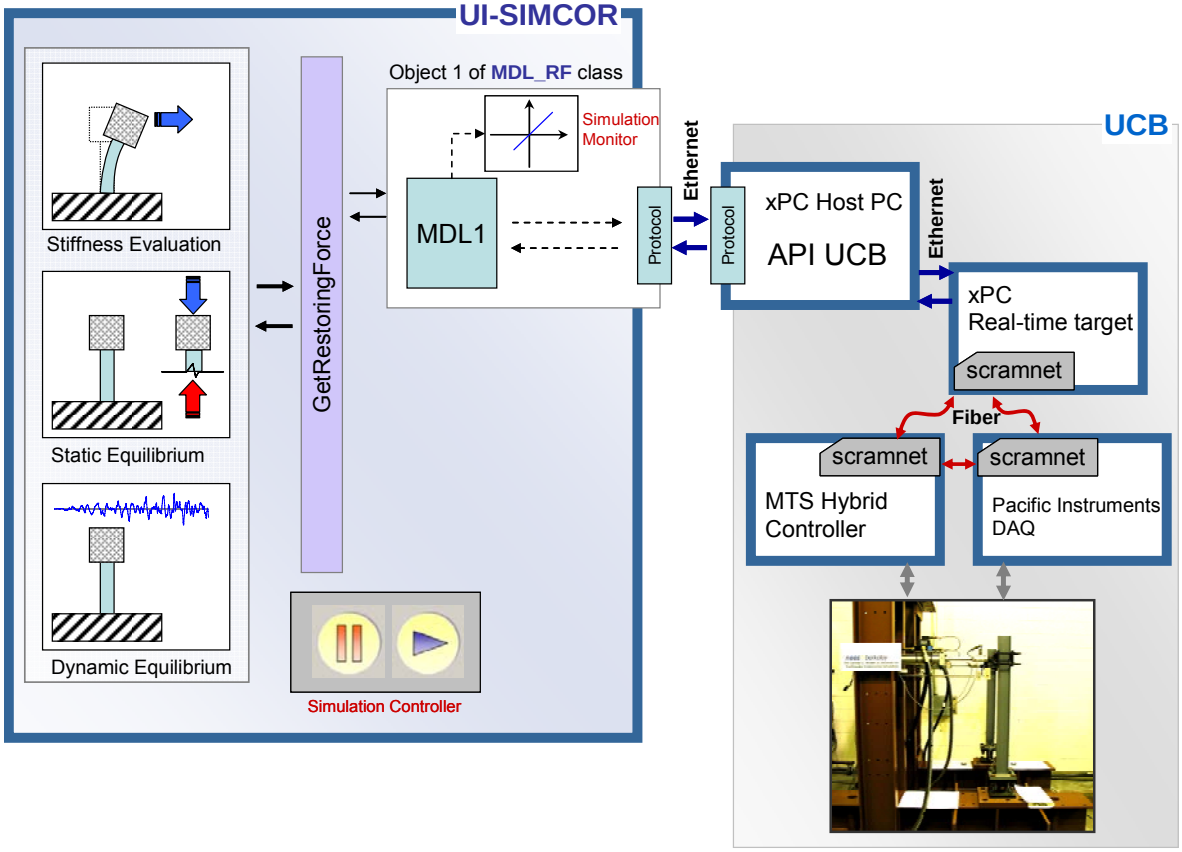


Figure 58 Configuration of hybrid simulation framework at UCB with UI-SIMCOR

Two processes are required for this test, one for UI-SIMCOR and the other one for API module. Both processes can be run in a single computer or in two computers. A single computer was used in this test. The procedure for running this test is given below.

The default value of the displacement limit is 6. If the target displacement which will be sent to xPC Real-time target is greater than the displacement limit, the test will be stopped with warning message. If you want modify the displacement limit, open the API_Main and modify Disp_Limit variable at line 17.

1. Run a MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
2. Type **API_Main**, then you will see the message box confirming the displacement limit as shown in Figure 59.

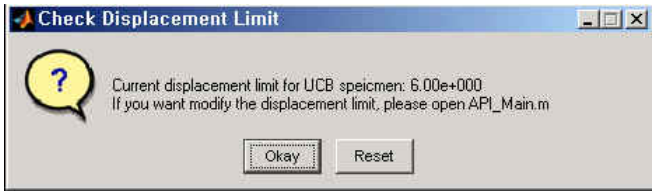

Check Displacement Limit
Current displacement limit for UCB speicmen: 6.00e+000
If you want modify the displacement limit, please open API_Main.m
Okay
Reset

Figure 59 Warning message for the displacement limit

a. If the displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 11999 …" in a MATLAB command window. IP address and port number are dependent on experimental configuration.
b. If you want modify the displacement limit, click **Reset** button, then the **API_Main** file is opened automatically. Modify the Disp_Limit variable at line 17.
c. If you want to try the pushover test by numerical simulation, then type **API_Main_sim** instead of **API_Main**.

Now ready to run the pushover test – This test will run automatically

3. Run another MATLAB for the pushover test and change the directory to C:\SIMCOR\03_Examples\UCB\PushoverTest\00_Coordinator
4. Type **PushOver** and enter in MATLAB command window to run the pushover test.
   a. One GUI for monitoring window as shown in Figure 60 will popup.
   b. Another simulation monitor of GUI as shown in Figure 61 for UCB site will be displayed in the MATLAB window for **API_Main**.
   c. **The default value of maximum displacement for pushover test is 2.** If you want to modify the maximum value, open the **PushOver** and modify the disp_scale variable at line 66.
   d. This will run automatically, so make sure the displacement limit.

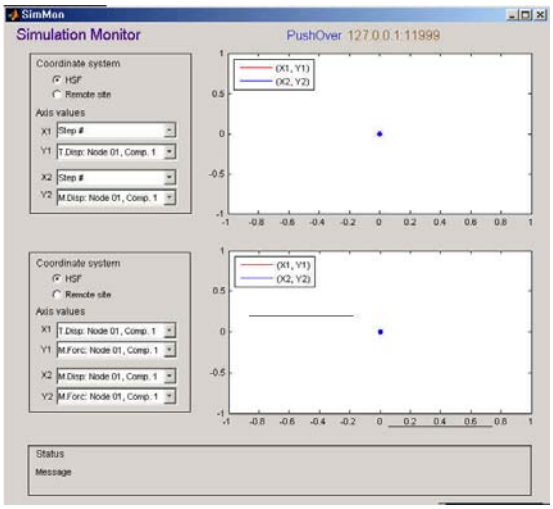


Figure 60 Monitoring window for pushover test

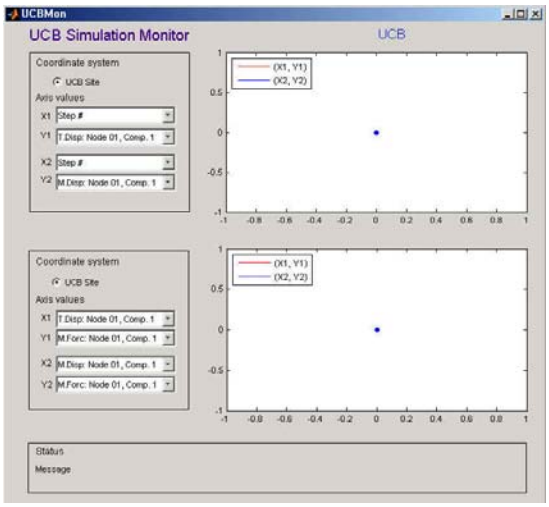


Figure 61 Monitoring window for UCB site

Results

Following output files will be saved in the following folders,

C:\SMCOR\03_Examples\UCB\PushoverTest\00_Coordinator

MDL00_recv.txt	Measured displacement and force of specimen
NetwkLog.txt	Communication log file

C:\SIMCOR\04_API\01_UCB

NetwkLog.txt	Communication log file
UCB_Results.txt	Target displacement, measured displacement and force at UCB site

The pushover test result is shown in Figure 62 and the analytical model was developed by using ZEUS-NL based on these results.

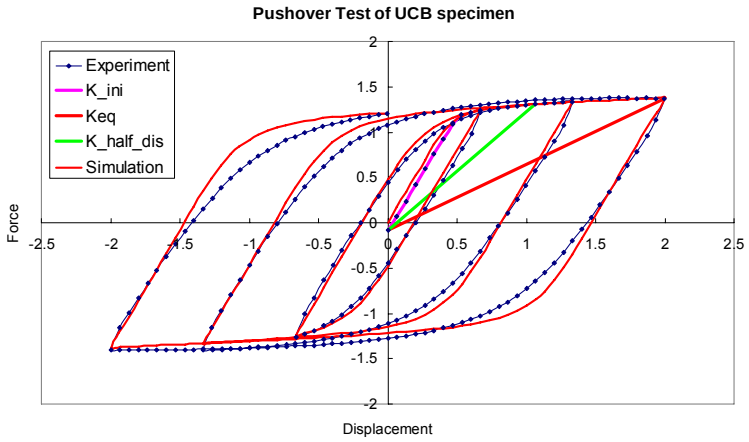


Figure 62 Comparison between experiment and simulation – pushover test

9.1.4 SDOF example

A dynamic analysis of a cantilever column with a lumped mass explained in section 8.1 is used here to verify the UI-SIMCOR. The column is replaced with the specimen at UCB.

The simulation configuration file for this experiment is identical to section 8.1 except the scale factor. Calculating scale factors for experimental site will be explained in section 9.4.

Running Procedure

1. Run a MATLAB for UI-SIMCOR and change the directory to C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
2. Type **UI_SimCor** and enter in MATLAB command window to run UI-SIMCOR.

New simulation
Please backup previous simulation results if necessary. All previous files will be deleted.
Okay
Cancel

Figure 63 Warning message

   a. Click **Okay** button, you will see the initialize message in a MATLAB command window. All previous files will be deleted, so if necessary backup the previous test results.
   b. Two popup windows will be displayed, one window for control and other window for monitoring will popup. In this example, only one monitoring window will be displayed as this example has only one remote site.
3. Run another MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
4. Type **API_Main**, you will see the message box confirming the displacement limit as shown in Figure 59.
   a. Similar to the pushover test, **the default value of displacement limit of the hybrid simulation is 6.**
   b. If you want to modify the displacement limit, click **Reset** button, then the **API_Main** file is opened automatically. Modify the Disp_Limit variable at line 17.
   c. If displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 11999 …" in a MATLAB command window. IP address and port number are dependent on experimental configuration.
   d. It is highly recommended to run the simulation by using **API_Main_sim** before the real experiment.

Now, ready to run experiment

5. Click **Establish Connection** button in UI-SIMCOR control window. You will see some messages indicating that the connection is established in both MATLAB command windows and another simulation monitor of GUI for UCB site will be displayed in the MATLAB for **API_Main** as shown in Figure 61.
   a. If the UI-SIMCOR run in the other computer or the other site (i.e., UIUC), then this GUI helps UCB site seeing current status of experiment.
6. Click **Stiffness Evaluation** button in UI-SIMCOR. UI-SIMCOR will either read stiffness of specimen from file or run stiffness test depending on the parameter in configuration file. When the stiffness is manually provided, the stiffness matrix each module should be provided in the files located in the 00_Coordinator folder. In this test, the predefined stiffness matrix is used.
7. Click **Apply Static Loading** button. In this stage, the gravity force is applied. There is no plan to apply gravity as this exemplary test is to demonstrate the efficacy of hybrid simulation framework.
8. Click **Start PSD Test** to run experiment. The target displacement and feedback displacement and force will be displayed in the monitoring window and UCB monitoring window.
9. Click **Disconnect Modules** after finishing hybrid test to disconnect UI-SIMCOR from xPC Real-time target. You will see some messages indicating that the communication is disconnected in both MATLAB windows.

Results

Following output files will be saved in the following folders,

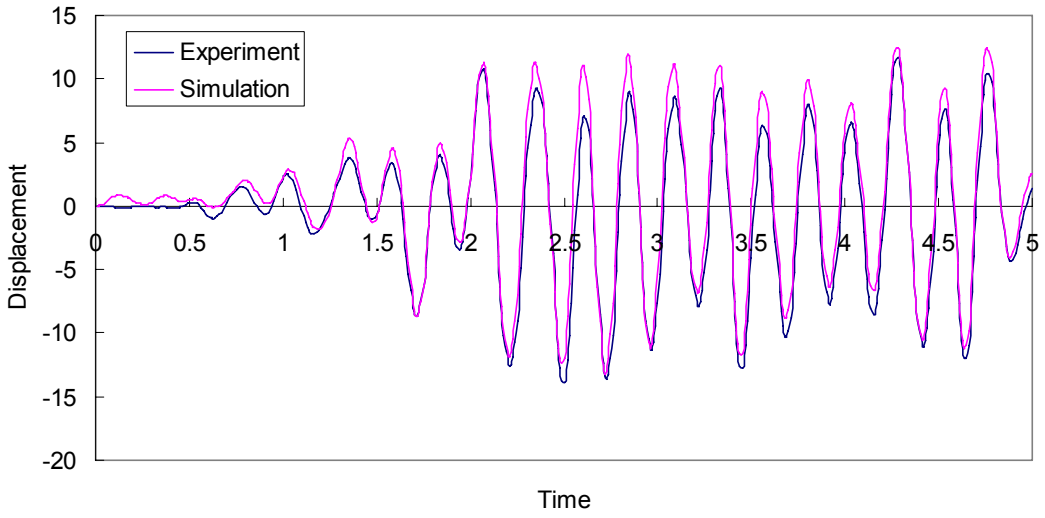
C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator

Global_K.txt	Stiffness matrix from initial stiffness evaluation
MDL01_K.txt	Stiffness matrix of module 1
MDL01_recv.txt	Measured displacement and force of module 1
NetwkLog.txt	Communication log file
NodeDisp.txt	Nodal displacements

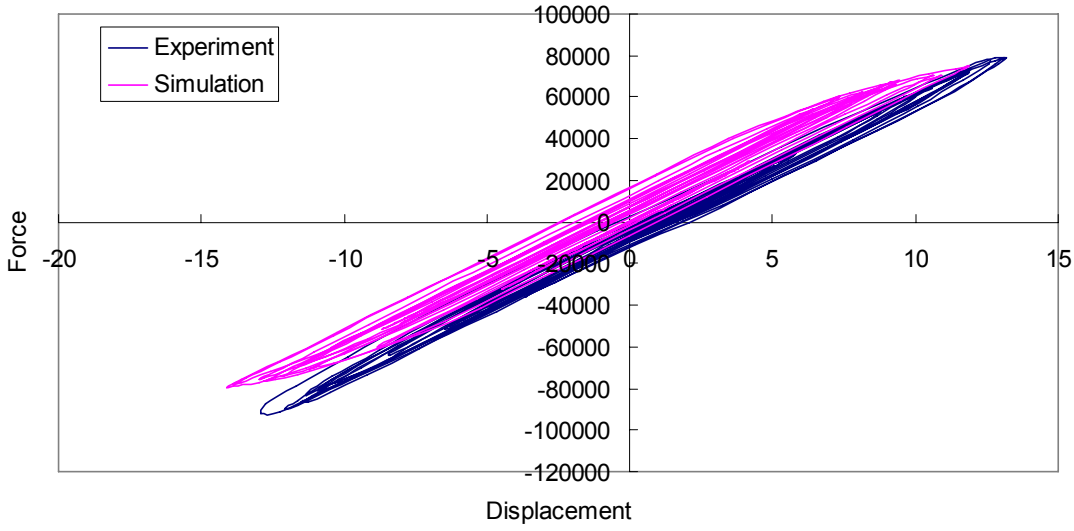
C:\SIMCOR\04_API\01_UCB

NetwkLog.txt	Communication log file
UCB_Results.txt	Target displacement, measured displacement and force at UCB site

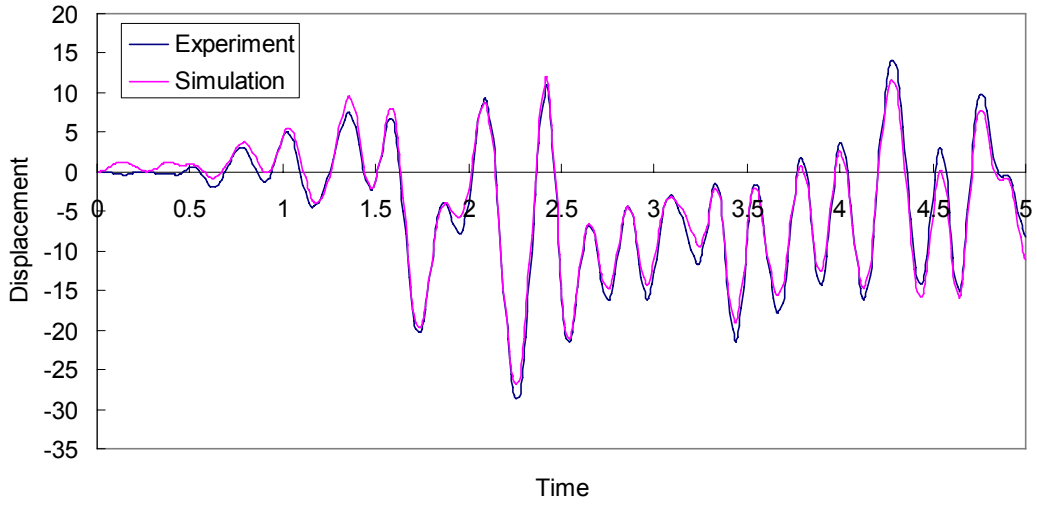
Two tests with different peak ground accelerations of input earthquake were conducted and the results are shown in Figures 64 and 65.



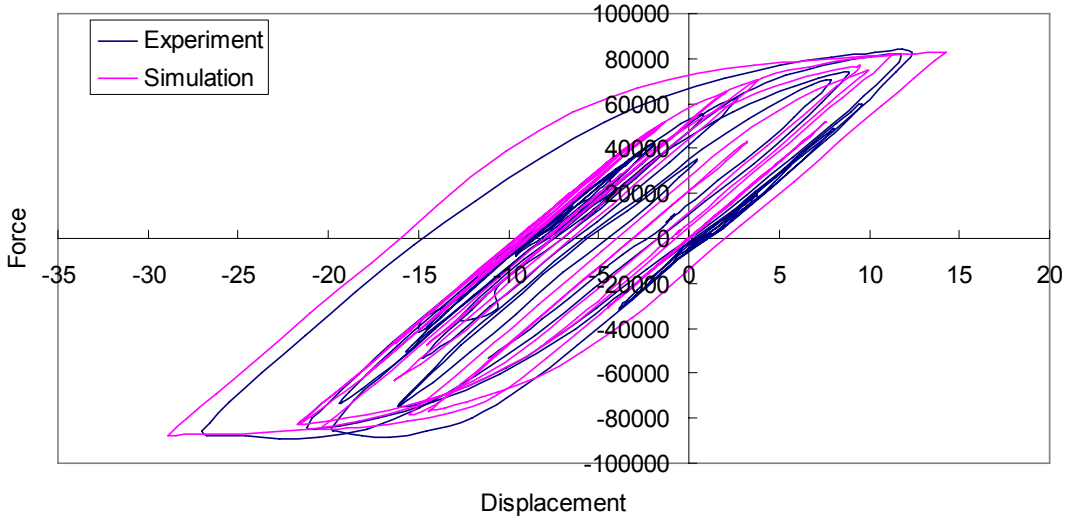
(a) Horizontal displacement at top node in the HSF



(b) Force-displacement relationship at top node in the HSF
Figure 64 Pseudo dynamic test results – SDOF test 1



(a) Horizontal displacement at top node in the HSF



(b) Force-displacement relationship at top node in the HSF
Figure 65 Pseudo dynamic test results – SDOF test 2

There are some differences between experiment and simulation, because of the initial value in displacement and force during the experiment.

9.1.5 MOST example

MOST example used in section 8.4 is used in this section. The structural configuration is except scale factors also same as section 8.4.

The modules 1 and 2 were simulated using the ZEUS-NL and module 3 was replaced by the specimen at UCB.

Running procedure

The running procedure of the MOST example is very similar to that of the SDOF system except, there are two addition simulation parts.

1. Go to C:\SIMCOR\03_Examples\UCB\MOST\01_Left_ZEUS folder and double click the NEESSAM_LabVIEW2 to run API for simulation part (module 1). You will see the API similar with Figure 23.
2. Similar to step 1, go to C:\SIMCOR\03_Examples\UCB\MOST\02_Middle_ZEUS folder and double click the NEESSAM_LabVIEW2 to run API for another simulation part (module 2). You will see the API similar with Figure 23.
3. Run a MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
4. Type **API_Main**, you will see the message box confirming the displacement limit as shown in Figure 59.
   a. Similar to the pushover test, **the default value of displacement limit of the hybrid simulation is 6.**
   b. If you want to modify the displacement limit, click **Reset** button, then the **API_Main** file is opened automatically. Modify the Disp_Limit variable at line 17.
   c. If displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 11999 …" in a MATLAB command window. The IP address and port number are dependent on experimental configuration.
   d. It is highly recommended to run the simulation by using **API_Main_sim** before the real experiment.
5. Run another MATLAB for UI-SIMCOR and change the directory to C:\SIMCOR\03_Examples\UCB\MOST\00_Coordinator
6. Type **UI_SimCor** and enter in MATLAB command window to run UI-SIMCOR. You will see the Figure 63 again.
   a. Click **Okay** button, you will see the initialize message in a MATLAB command window. All previous files will be deleted, so if necessary backup the previous test results.
   b. One control window and three monitoring windows which correspond to each module will be displayed.

Now, ready to run experiment

7. Click **Establish Connection** button in UI-SIMCOR control window. You will see some messages indicating that the connection is established in both MATLAB command windows and in two APIs for simulation part. Furthermore another simulation monitor of GUI for UCB site will be displayed in the MATLAB for **API_Main** as shown in Figure 61.
   a. If the UI-SIMCOR run in the other computer or the other site (i.e., UIUC), then this GUI helps UCB site seeing current status of experiment.
8. Click **Stiffness Evaluation** button in UI-SIMCOR. UI-SIMCOR will either read stiffness of specimen from file or run stiffness test depending on the parameter in configuration file. When the stiffness is manually provided, the stiffness matrix each module should be provided in the files located in the 00_Coordinator folder. In this test, the predefined stiffness matrix is used.
9. Click **Apply Static Loading** button. In this stage, the gravity force is applied. There is no plan to apply gravity as this exemplary test is to demonstrate the efficacy of hybrid simulation framework.
10. Click **Start PSD Test** to run experiment. The target displacement and feedback displacement and force will be displayed in the monitoring window and UCB monitoring window.
11. Click **Disconnect Modules** after finishing hybrid simulation to disconnect UI-SIMCOR from xPC Real-time target. You will see some messages indicating that the communication is disconnected in both MATLAB windows and in two APIs for simulation parts.

Results

Following output files will be saved in the following folders,

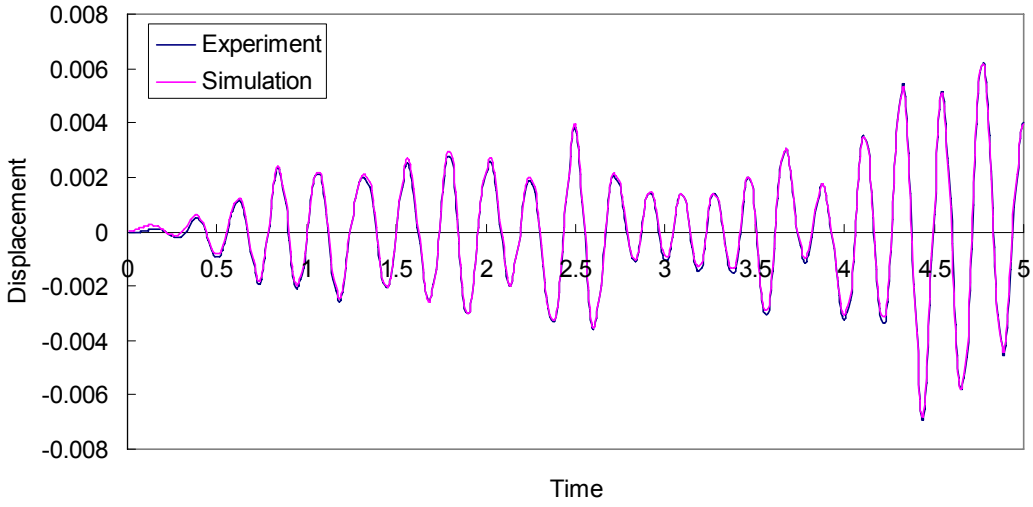
C:\SIMCOR\03_Examples\UCB\MOST\00_Coordinator

Global_K.txt	Stiffness matrix from initial stiffness evaluation
MDL01_K.txt	Stiffness matrix of module 1
MDL02_K.txt	Stiffness matrix of module 2
MDL03_K.txt	Stiffness matrix of module 3
MDL01_recv.txt	Measured displacement and force of module 1
MDL02_recv.txt	Measured displacement and force of module 2
MDL03_recv.txt	Measured displacement and force of module 3
NetwkLog.txt	Communication log file
NodeDisp.txt	Nodal displacements

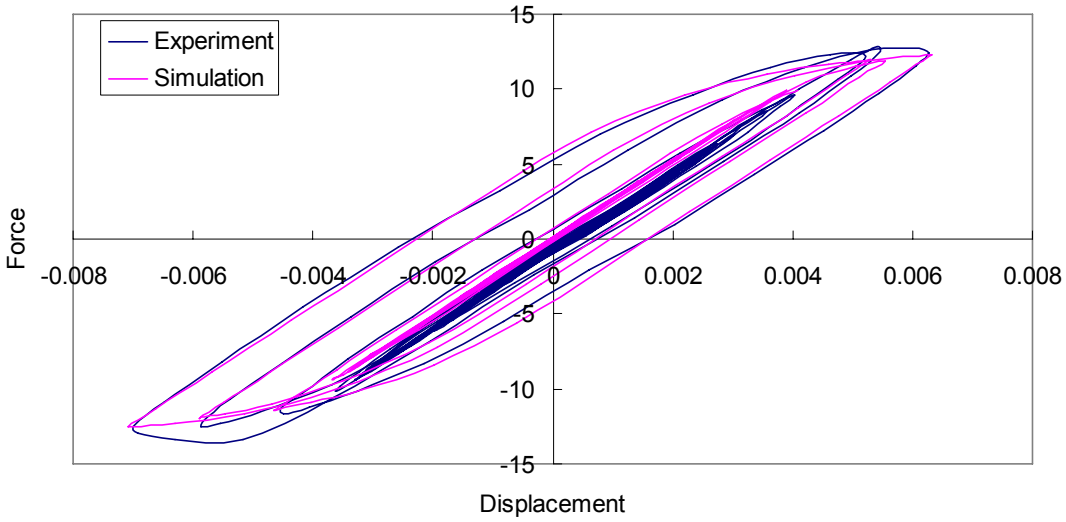
C:\SIMCOR\04_API\01_UCB

NetwkLog.txt	Communication log file
UCB_Results.txt	Target displacement, measured displacement and force at UCB site

Two tests with different peak ground accelerations of input earthquake were conducted and the results are shown in Figures 66 and 67.

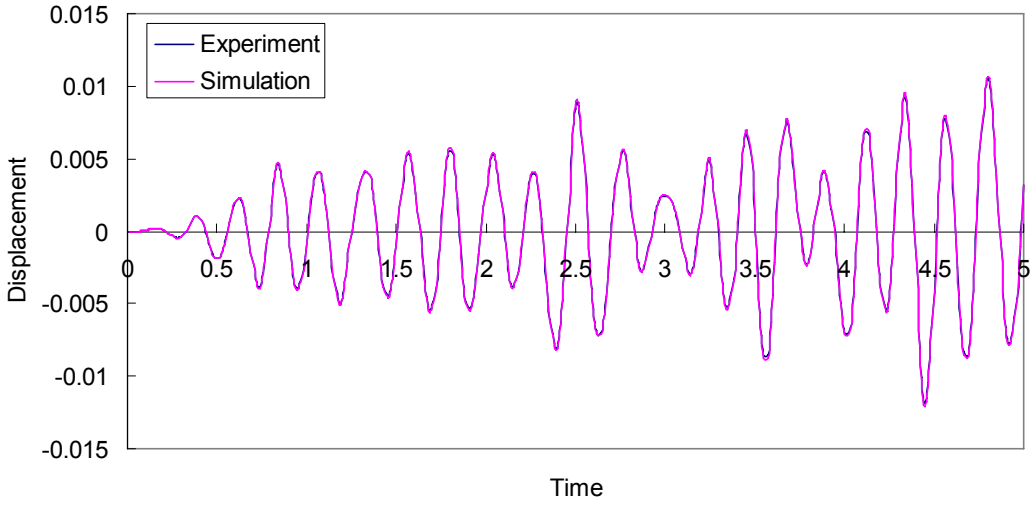


(a) Horizontal displacement at CP3 in the HSF

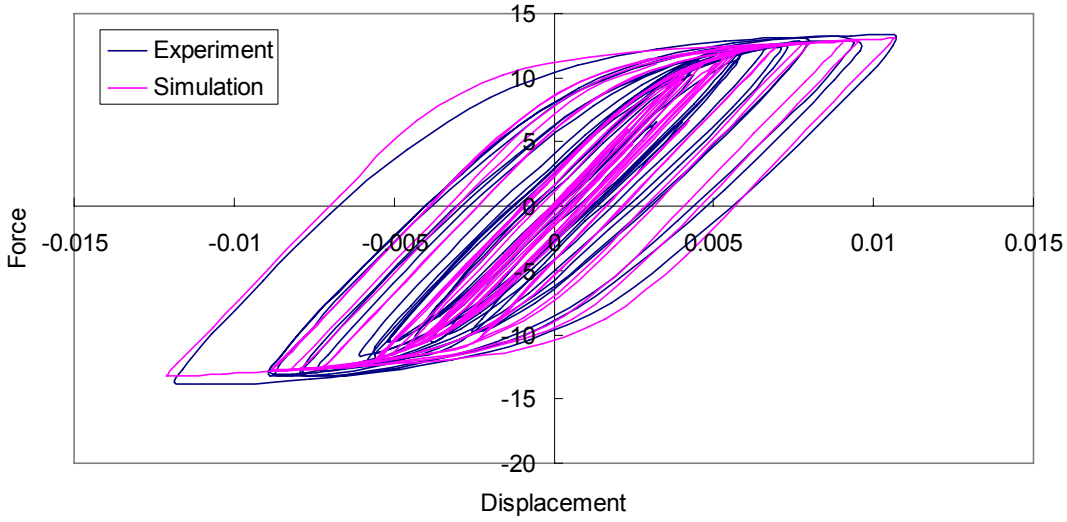


(b) Force-displacement relationship at CP3 HSF

Figure 66 Pseudo dynamic test results – MOST test 1



(a) Horizontal displacement at CP3 in the HSF



(b) Force-displacement relationship at CP3 in the HSF
Figure 67 Pseudo dynamic test results – MOST test 2

The test results are better than those of SDOF example, because most part of the structures is analytical model except one component of horizontal DOF.

9.1.6 Summary

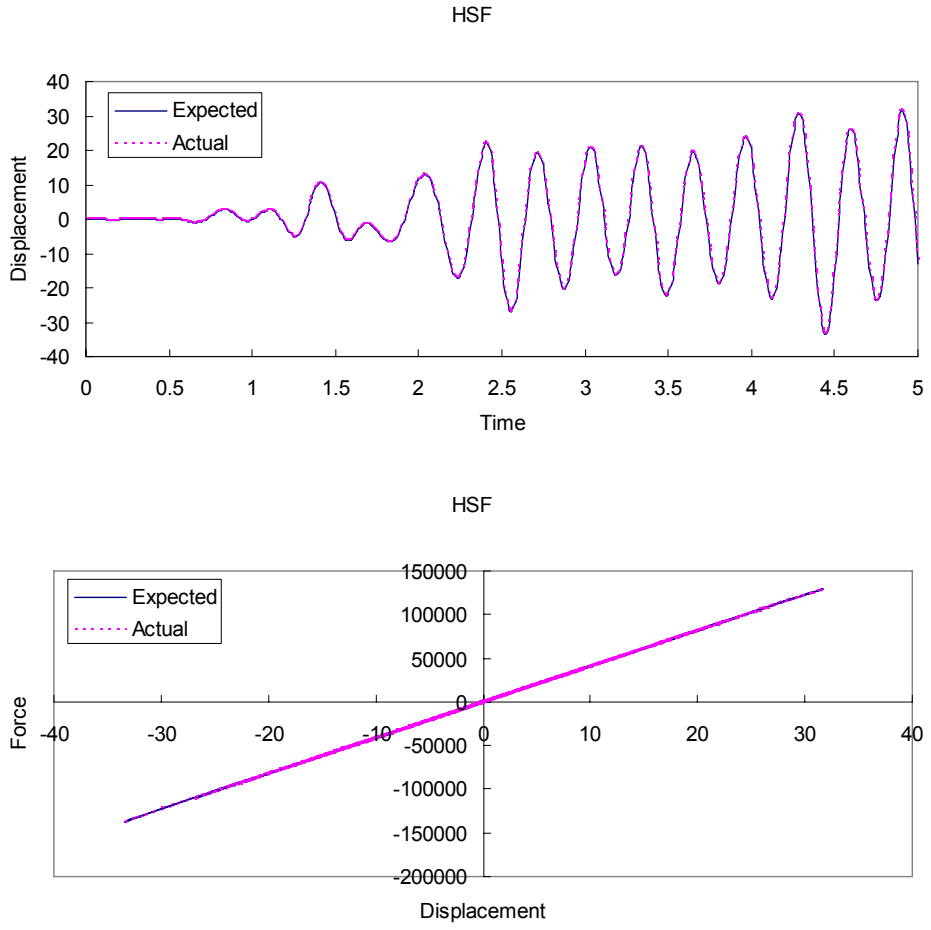
The two-site hybrid test between UIUC and UCB was conducted to verify and demonstrate the efficacy of recently enhanced UI-SIMCOR. The μNEES at UCB was used in this test and the functionality of UI-SIMCOR with μNEES specimen was verified and UCB site is ready for three-site hybrid test.

9.2 Two-site Experiment between UIUC and UCB

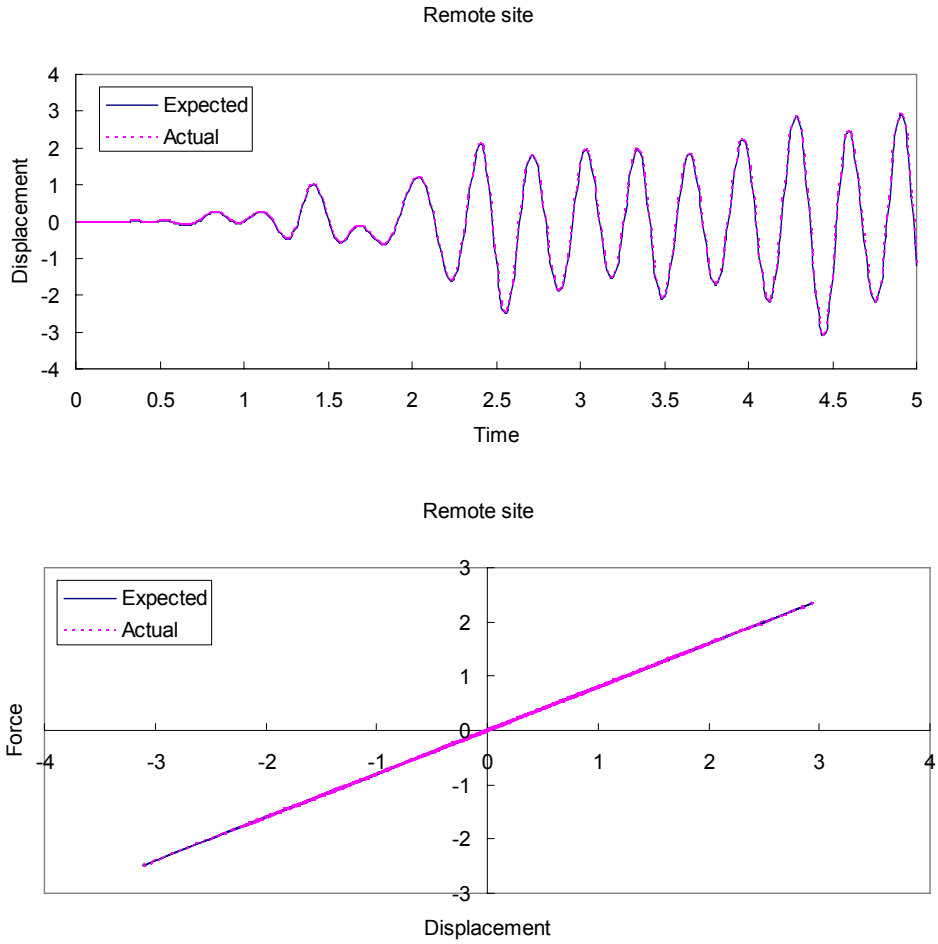
The two-site hybrid test between UIUC and UCB using recently enhanced UI-SIMCOR were conducted at October 4, 2006 using SDOF example in the Section 8.1.

9.2.1 Hybrid test by simulation at UCB site only

The purpose of this step is to verify the configuration of newly installed UI-SIMCOR at UCB. The results are shown in Figure 68 and the "Expected" and "Actual" mean the simulation results at UIUC and UCB, respectively. As shown in figure, the test results simulated at UIUC and UCB is identical, so the configuration of newly installed UI-SIMCOR at UCB was verified.



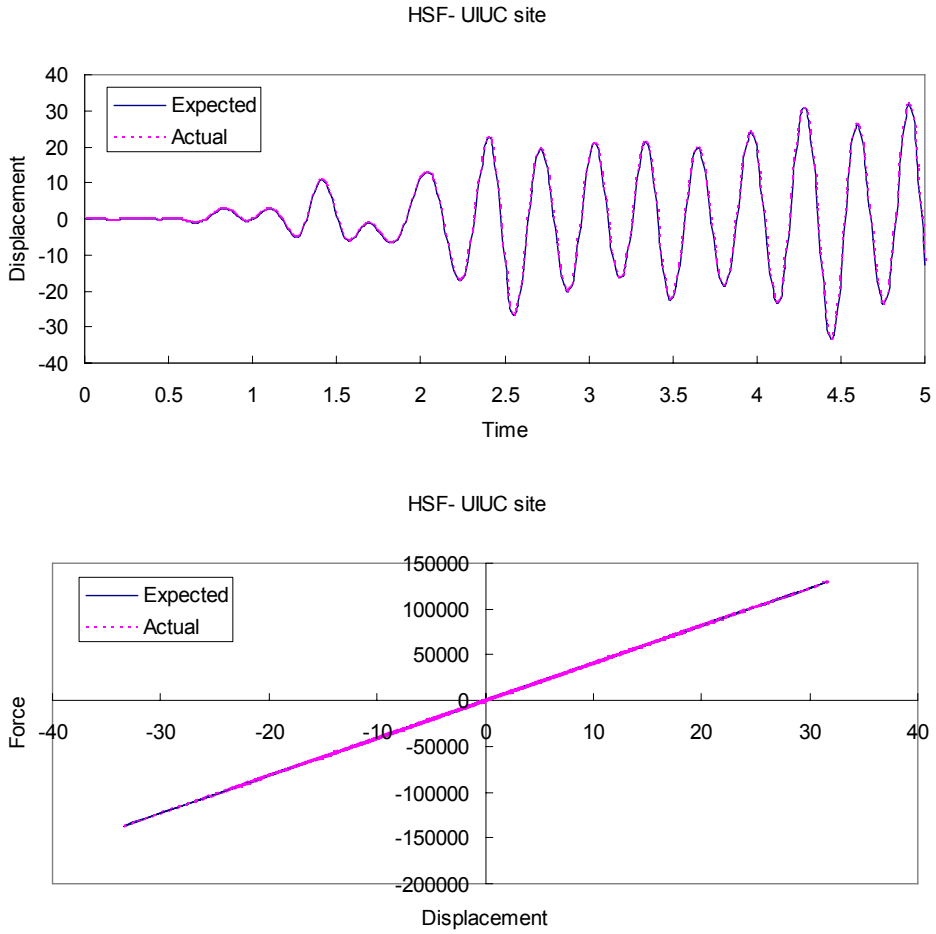
(a) Hybrid simulation framework
Figure 68 Simulation results



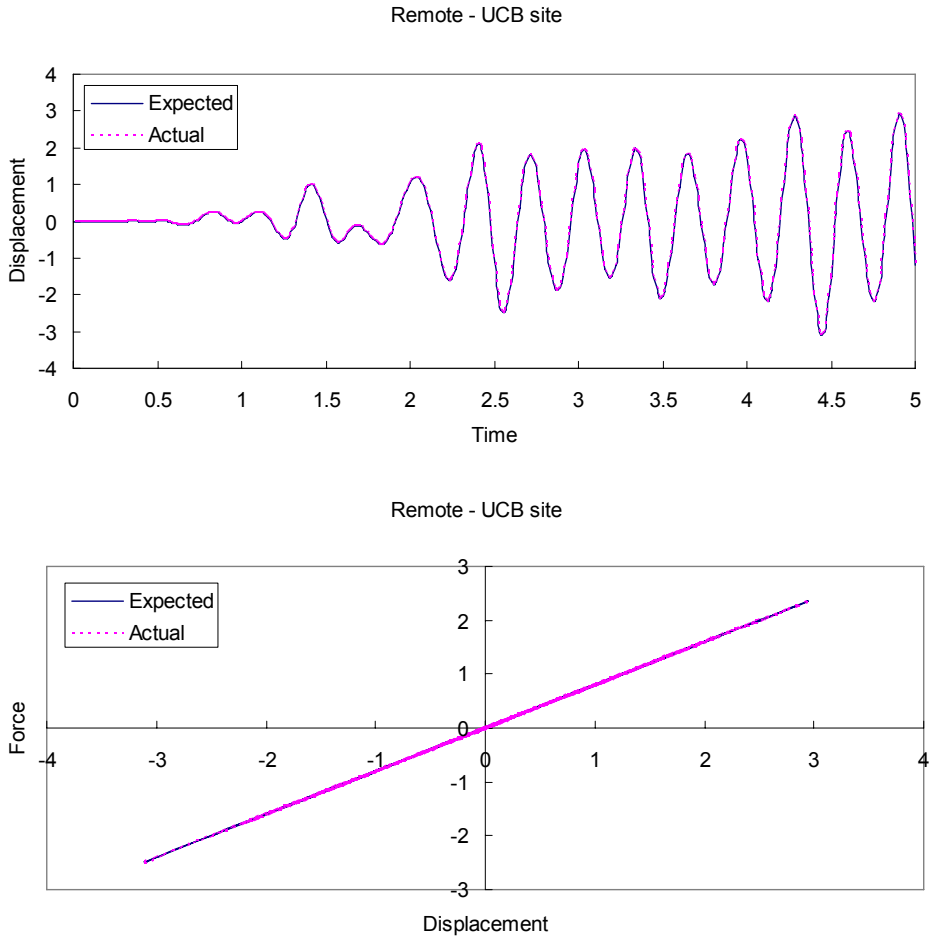
(b) Remote site
Figure 68 Simulation results - continued

9.2.2 Hybrid test between UIUC and UCB by simulation

After verification of the configuration of UI-SIMCOR, hybrid test between UIUC and UCB was conducted by simulation to verify the communication. The results are shown in Figure 69 and the "Expected" and "Actual" mean the simulation results at UIUC only and at UIUC and UCB, respectively. As shown in figure, the test results simulated at UIUC and UIUC and UCB is identical, so the communication between UIUC and UCB was verified.



(a) Hybrid simulation framework
Figure 69 Simulation results



(a) Hybrid simulation framework
Figure 69 Simulation results - continued

9.2.3 One-site experiment at UCB

The coupon will be used in this two-site hybrid test is very similar to coupon used in the previous pushover test. Before, the hybrid test the one-site experiment at UCB was conducted to verify the configuration of xPC Real-time target and the test results are shown in Figure 70. It took 3 min and 20 sec for 500 steps (0.4 sec/step) to finish the pseudo dynamic stage in UI-SIMCOR. There are little difference between simulation and experiment because of difference of coupon at UCB specimen. The analytical model of μNEES specimen at UCB was obtained by using the pushover test results conducted during August 9, 2006 ~ August 16, 2006. Furthermore, the characteristic of specimen at UCB is highly dependent on the coupon installed in the specimen. The coupon used in this test is little bit different from the coupon used for pushover test, so there are little difference between simulation and experiment.

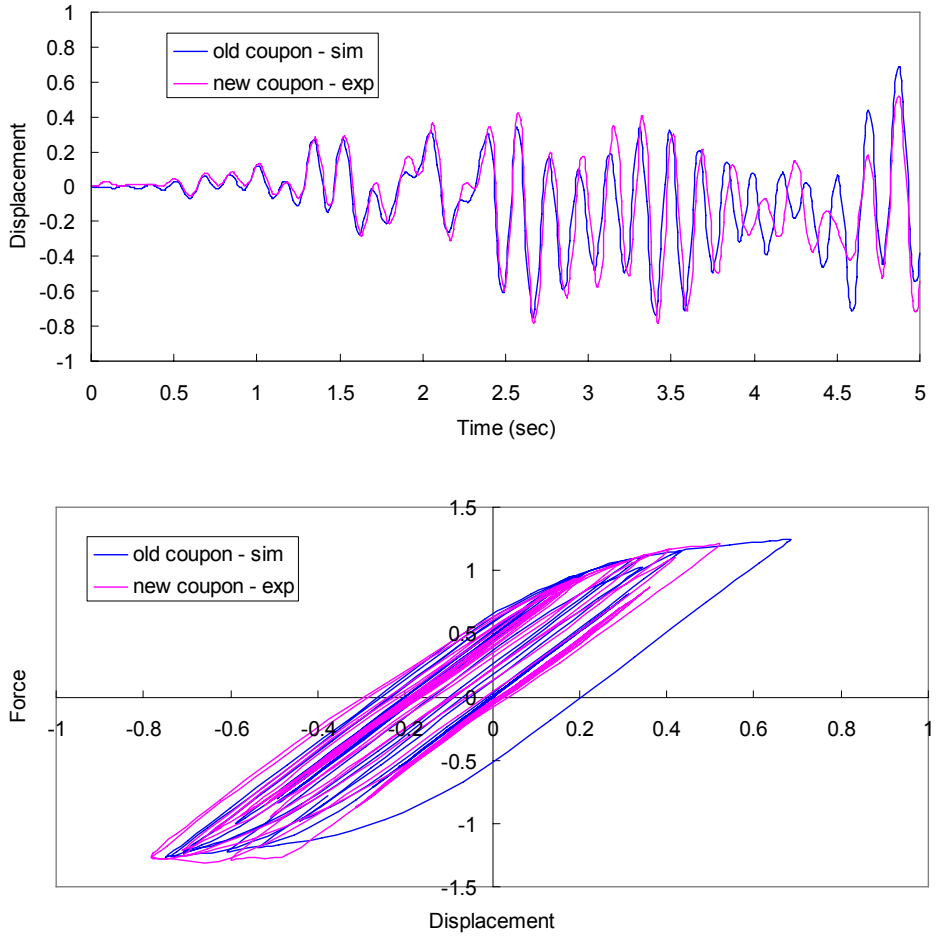


Figure 70 Experiment results

9.2.4 Two-site experiment between UIUC and UCB

Finally, two-site experiment between UIUC and UCB was conducted and the results are shown in Figure 71. It took 3 min and 16 sec for 500 steps (0.4 sec/step) to finish the pseudo dynamic stage in UI-SIMCOR and the two-site test was successfully accomplished.

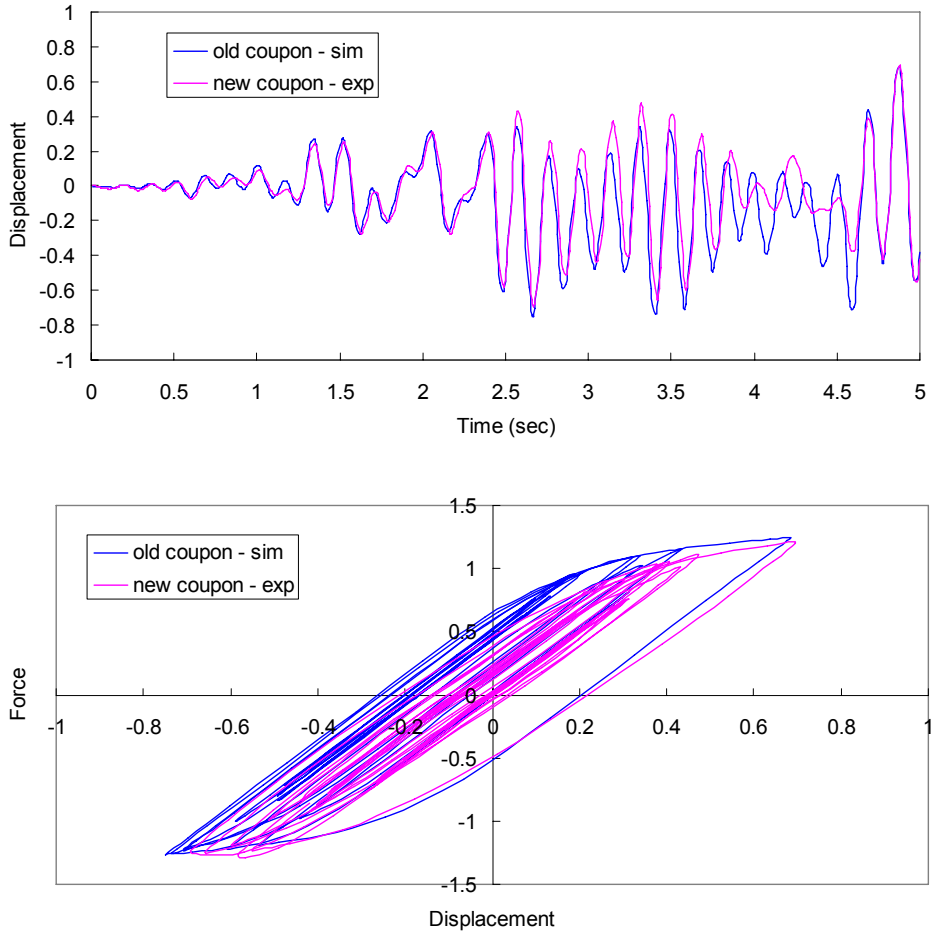


Figure 71 Experiment results

9.3 Two-site Experiment between UIUC and SDSC

Two-site hybrid test between UIUC and SDSC was conducted at September 12, 2006 and these experiments were very successful.

The structural configuration was similar to the MOST example with the only difference that the left column was assumed pinned at the top to be able to conduct the test using two MiniMOST 1 systems.

The modules 1 and 3 in MOST example are replaced with MiniMOST 1 at SDSC and UIUC, respectively, and module 2 is simulated at UIUC using ZEUS-NL.

This test was conducted as a preliminary test for a three-site experiment among UIUC, UCB, and SDSC, so further explanation including running procedure is not given in this section. Instead all of related explanation will be given in the next section.

Figure 72 shows the comparison between experiment and simulation.

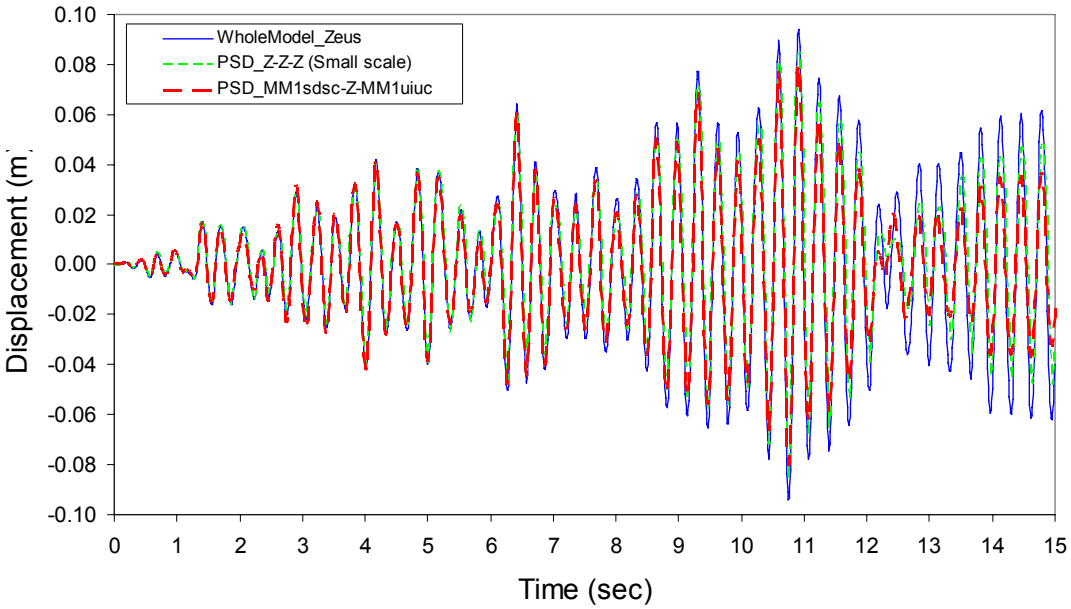


Figure 72 Horizontal displacement of left column

9.4 Three-site Experiment among UIUC, UCB, and SDSC

One-site and two-site experiments explained in Section 9.1 and 9.3 were preliminary tests for three-site hybrid test among UIUC, UCB, and SDSC. These tests were very successful so UIUC, UCB, and UCB sites are ready for three-site experiment. This section will explain the model for three-site hybrid test including calculation of scale factors. Finally, the results of three-site hybrid test will be explained.

9.4.1 Structural configuration

The main objective of a three-site hybrid test is to verify the recently enhanced UI-SIMCOR including communication. The example structure for a three-site hybrid test among UIUC, UCB, and SDSC is a bridge-like structure with four columns and five beams. This example has 6 control points and each control point only has one horizontal DOF. The material properties of this example are similar to those of MOST example (Nakata et. al., 2003). The hybrid simulation configuration of this three-site experiment is shown in Figure 73. Modules 1, 3, and 4 will be replaced with MiniMOST 1 at UIUC, μNEES at UCB, and MiniMOST 1 at SDSC, respectively and Module 2 will be modeled by ZEUS-NL (Elnashai et. al., 2006).

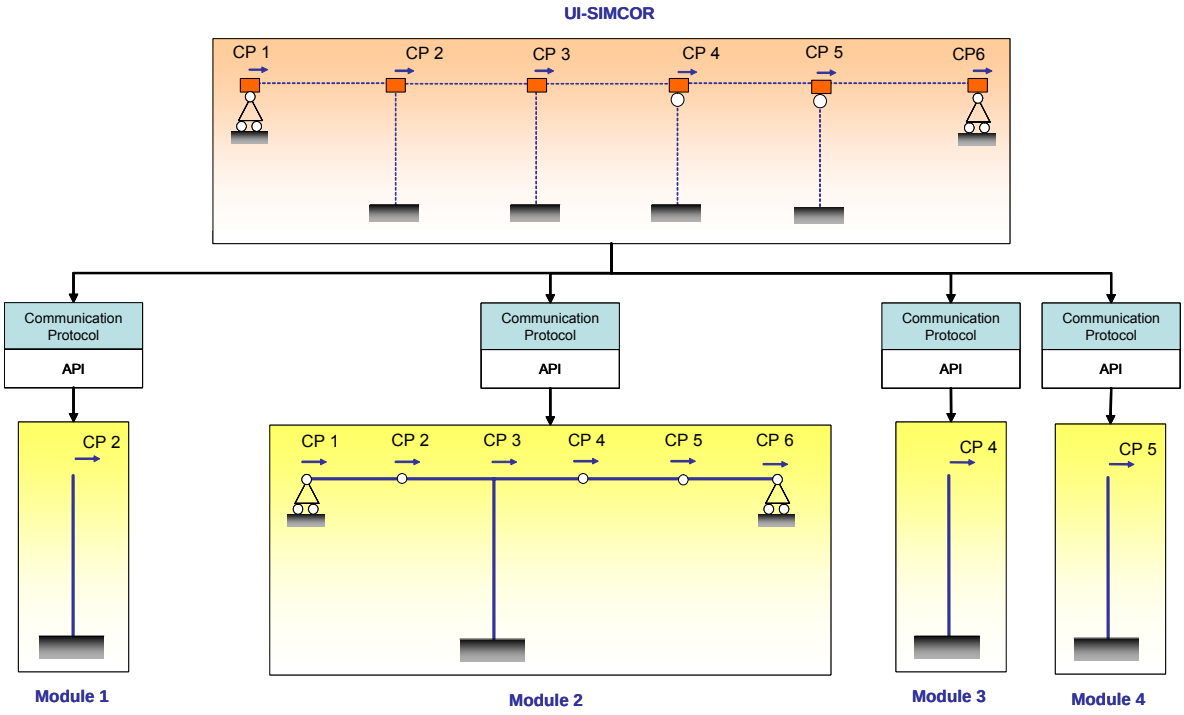


Figure 73 Hybrid simulation configuration of three-site experiment

9.4.2 Simulation results

Before the real experiment, hybrid test is conducted only by simulation using the model of each module at one computer. The scale factor of each site for UI-SIMCOR will be calculated using the stiffness of each module and responses. The input excitation used in this example is shown in Figure 74.

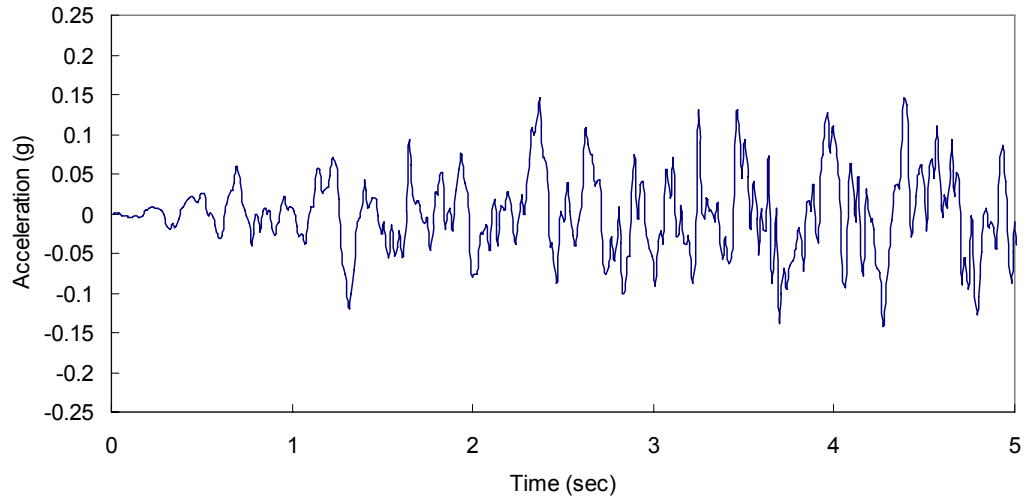


Figure 74 Input ground motion

Figure 75 shows the pseudo dynamic (PSD) test results and compared with whole model. Whole model and each module of PSD test are modeled by ZEUS-NL. The PSD results show good agreement with those of whole model.

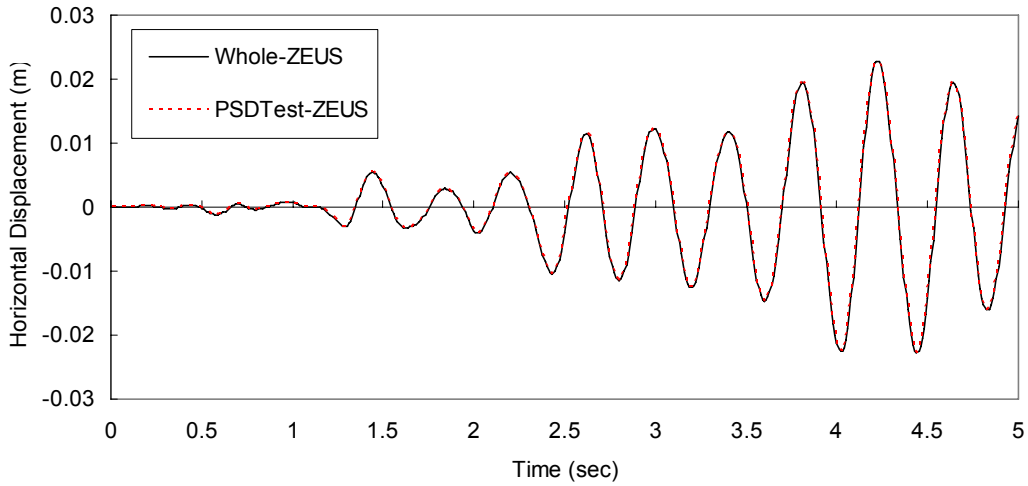


Figure 75 Horizontal displacement at CP2

The stiffness of each module can be calculated by structural parameters or stiffness evaluation step during PSD test by imposing single step displacement in UI-SIMCOR, or pushover test of each module in ZEUS-NL. In this example, the stiffness of each module is obtained by stiffness evaluation step during PSD test and shown in Table 2.

Table 2 Stiffness of each module

Module	Stiffness (kN/m)
Module 1	1.584×10^3
Module 3	1.584×10^3
Module 4	1.584×10^3

Because modules 1, 3, and 4 will be replaced with specimen at each site, the stiffness of those is needed to calculate scale factor of each site.

9.4.3 Specimen at each site

MiniMOST 1 @ UIUC

The module 1 in the three-site example will be replaced with MiniMOST 1 at UIUC as shown in Figure 76.

Figure 76 MiniMOST 1 at UIUC

Hybrid test between UIUC and SDSC with MiniMOST 1 at each site was conducted by Juan and Lawrence in September, 12, 2006 to test recently enhanced UI-SIMCOR. Based on these test results, the stiffness of MiniMOST 1 at UIUC can be calculated as shown in Figure 77.

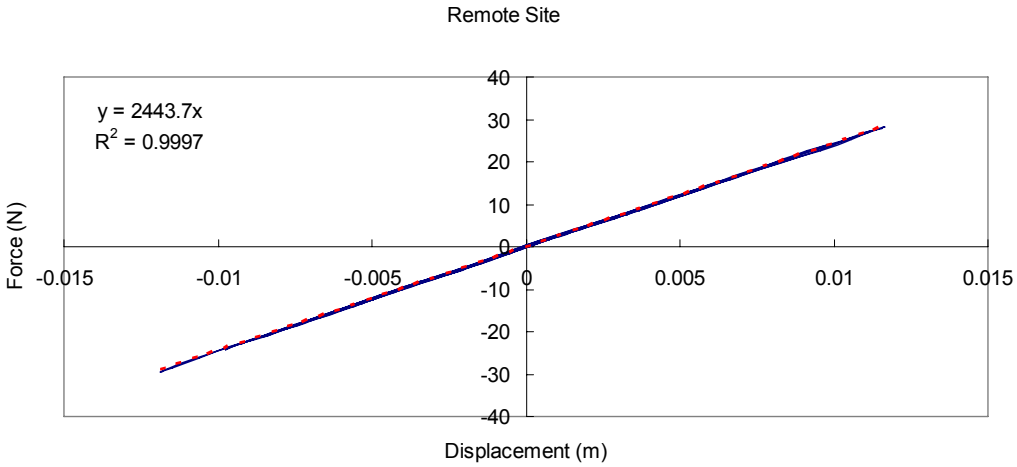


Figure 77 Stiffness of MiniMOST 1 at UIUC

μNEES @ UCB

The specimen at UCB explained in section 9.1 is used for three-site experiment.

MiniMOST 1 @ SDSC

Figure 78 shows MiniMOST 1 at SDSC and Figure 79 shows the test results conducted between UIUC and SDCS in September 12, 2006. The configuration of MiniMOST 1 at SDSC is very similar to MiniMOST 1 at UIUC.

Figure 78 MiniMOST 1 at SDSC

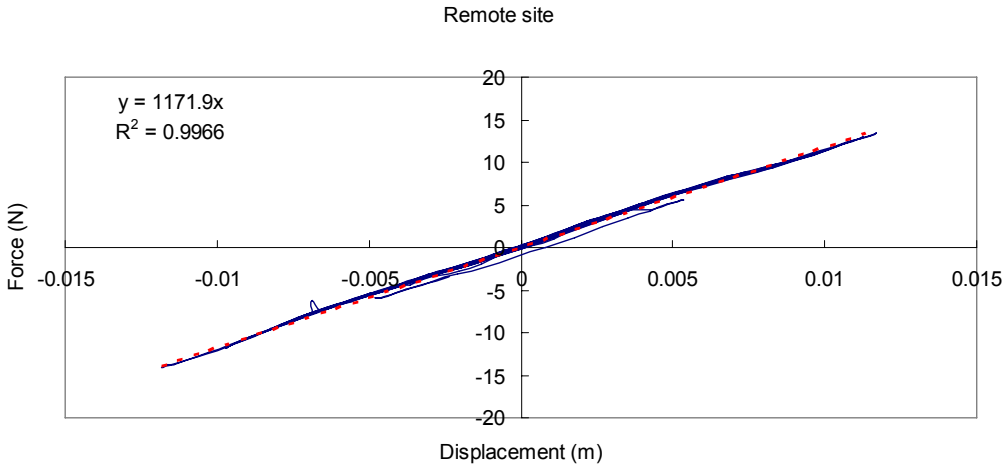


Figure 79 Stiffness of MiniMOST 1 at SDSC

9.4.4 Scale factor in UI-SIMCOR

In the configuration file of UI-SIMCOR (**SimConfig.m**), there is a variable, MDL(i).ScaleF, related to scale factor for displacement, rotation, force, and moment. Experimental specimens are not always in full scale. These factors can be used to apply scale factors. The displacement and rotation scale factors are multiplied before they are sent to module or experimental specimen. Measured forces and moments are divided with scale factors before used in the PSD algorithm.

The scale factor can also be used to adjust the target displacement within the limit of experiment specimen. For this exemplary test, the scale factor is used to insure that the target displacement which is calculated by UI-SIMCOR and will be sent to each experiment site is within the displacement limit of each site.

Based on the results of PSD test by simulation with original modules shown in Section 9.4.2, stiffness, maximum displacement and force of each module can be obtained as shown in Table 3.

Table 3 Properties of each module

Module	Stiffness	D_{max}	F_{max}
Module 1	1.584×10^3	0.0228	36.12
Module 3	1.584×10^3	0.0228	36.12
Module 4	1.584×10^3	0.0228	36.12

Furthermore, based on the results of test which was recently conducted at UIUC, UCB, and SDSC, following properties of each site can be obtained.

Table 4 Properties of each site

Site	Stiffness	D_{limit}	F_{max}
UIUC	2.444×10^3	0.01	24.44
UCB	1.230	2.0	2.46
SDSC	1.172×10^3	0.01	11.72

The displacement limit, D_{limit}, for UIUC, UCB, and SDSC is assumed as 0.01, 2, and 0.01, respectively. However, the actual displacement limit of each site is lager than theses values. For this test, the displacement limit of each site is assumed little smaller than actual one for safety issue. The MiniMOST 1 at UIUC and SDSC is linear specimen, whereas the μNEES at UCB is nonlinear specimen. Therefore, the equivalent stiffness obtained when the displacement is 1 is used for UCB specimen (Khalf_dis in Figure 62). However, this stiffness may or may not appropriate for calculation of scale factor depend on how much target displacement will be sent to the specimen.

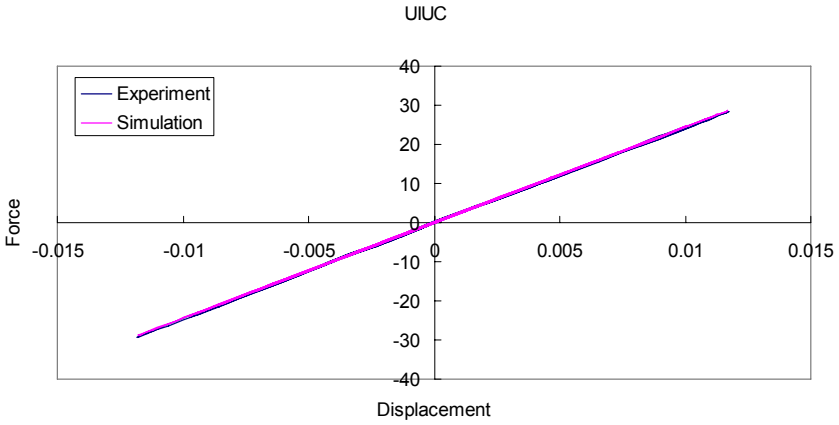
Finally, following scale factors of each site can be obtained using above results.

Table 5 Scale factor

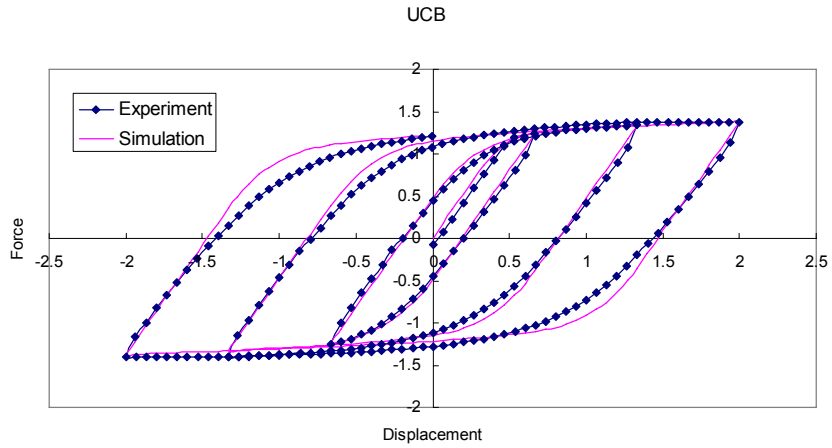
Site	Displacement	Rotation	Force	Moment
UIUC	0.439	1	0.677	1
UCB	87.719	1	0.068	1
SDSC	0.439	1	0.324	1

9.4.5 Analytical model of each site

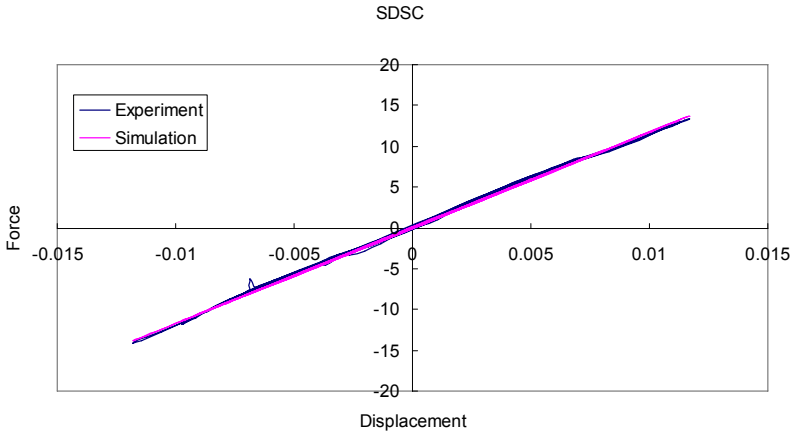
To predict and check the target displacement which will be sent to each site during the hybrid test, analytical model of specimen of each site is developed based on the experimental results by using ZEUS-NL. Figure 80 shows the comparison between experimental and analytical results of each site.



(a) MiniMOST 1 at UIUC



(b) μNEES at UCB



(c) MiniMOST 1 at SDSC

Figure 80 Comparison between experimental and analytical model of each site

As shown in Figure 80, the results of analytical model are well matched with those of experiment test, so theses analytical models could be used to estimate the target displacement during the hybrid test

9.4.6 Simulation results

The modules in the three-site example shown in Figure 73 are replaced with the specimen of each site as shown in Figure 81. The simulation results are shown in Figures 82 and 83 and the target displacement for each site is well within the displacement limit.

Figures 84 and 85 show the simulation results under magnified excitation. The input excitation is increased 1.8 times to increase the target displacement. In this case, same scale factors obtained in Section 9.4.4 are used. The target displacement for each site is also well within the displacement limit and these estimated target displacement will be sent to each site.

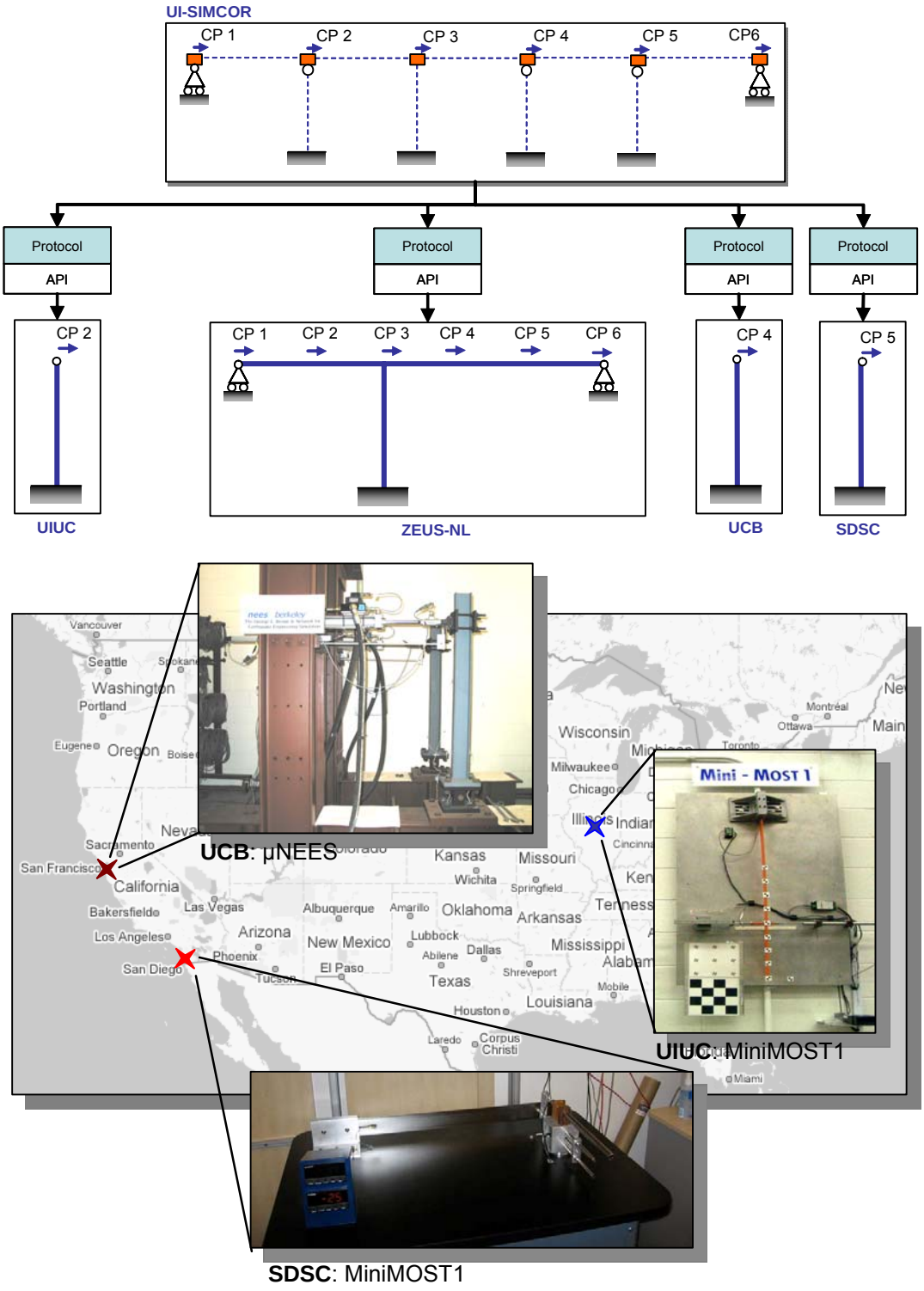
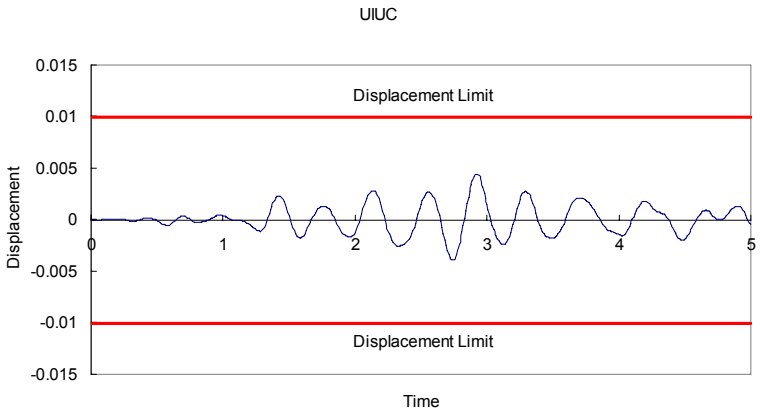
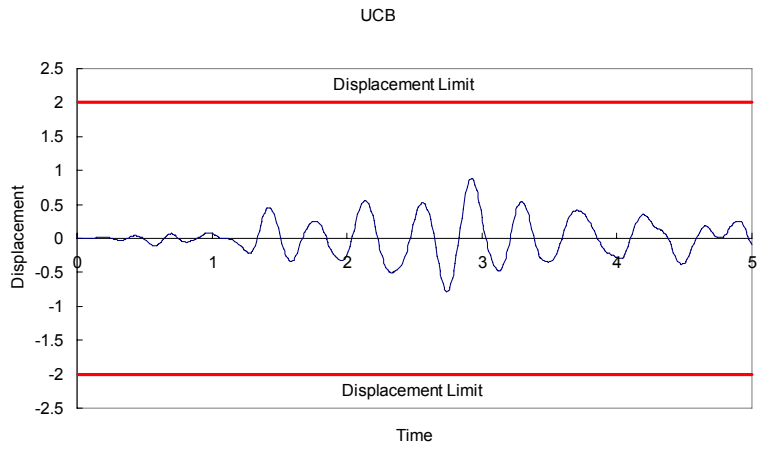


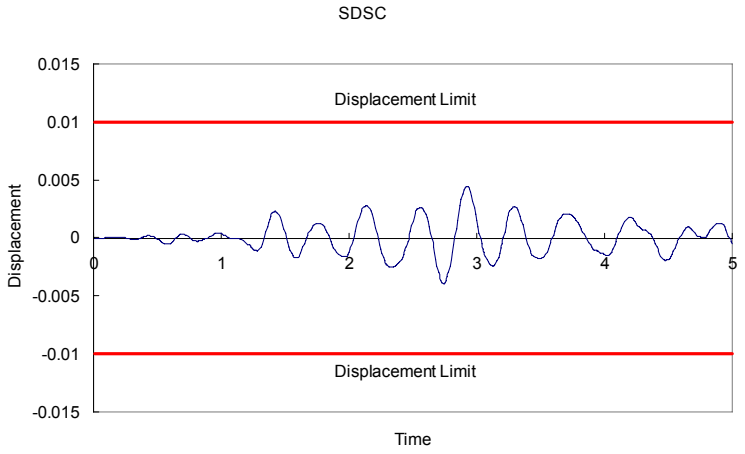
Figure 81 Hybrid simulation configuration of three-site experiment



(a) MiniMOST 1 at UIUC

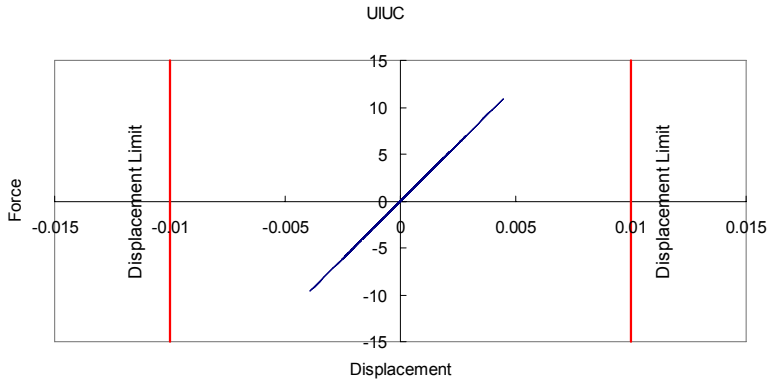


(b) μNEES at UCB

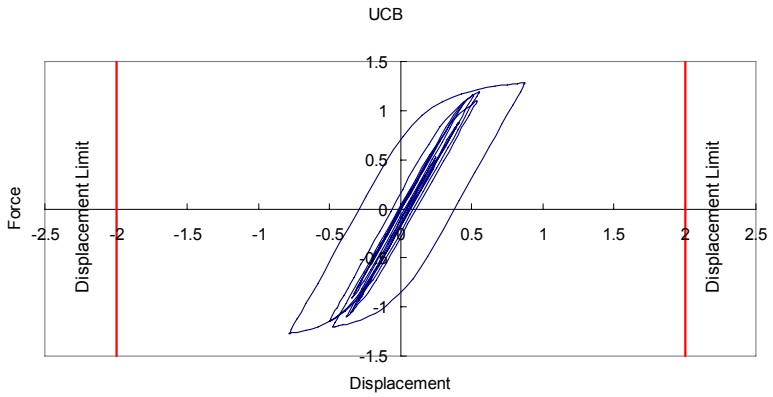


(c) MiniMOST 1 at UIUC

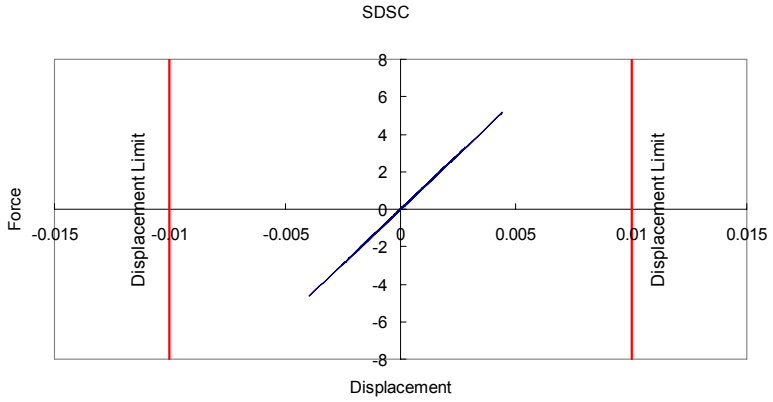
Figure 82 Hybrid test results – input case 1



(a) MiniMOST 1 at UIUC

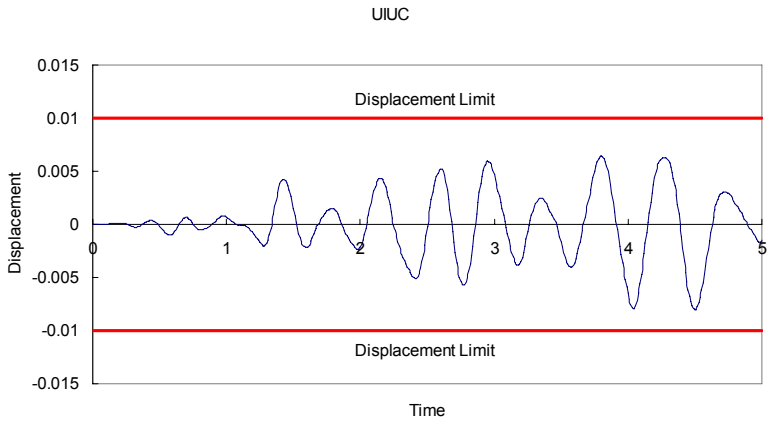


(b) μNEES at UCB

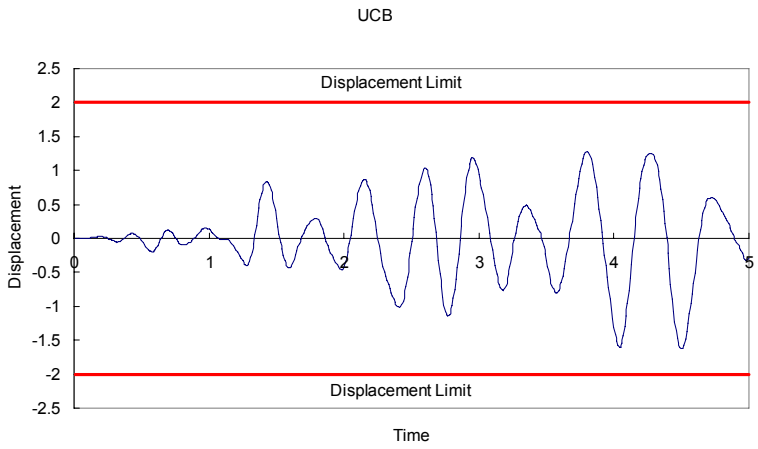


(c) MiniMOST 1 at UIUC

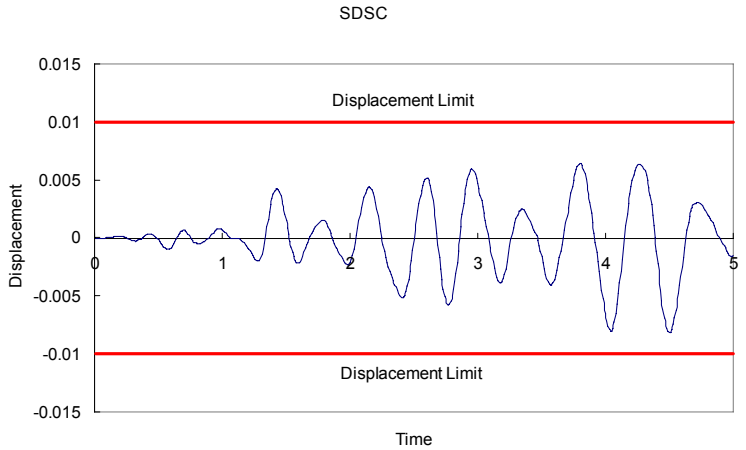
Figure 83 Hybrid test results – input case 1



(a) MiniMOST 1 at UIUC

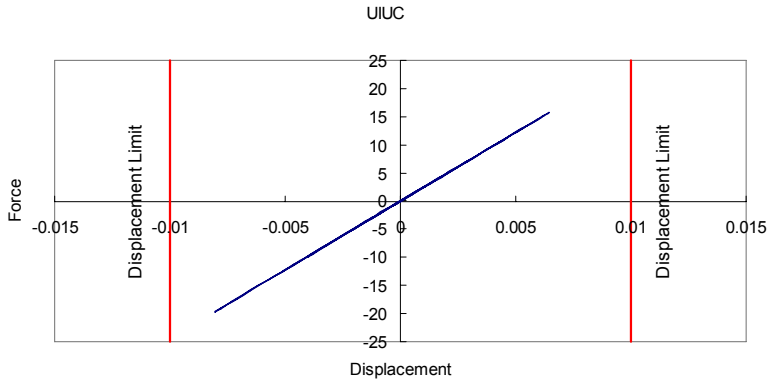


(b) μNEES at UCB

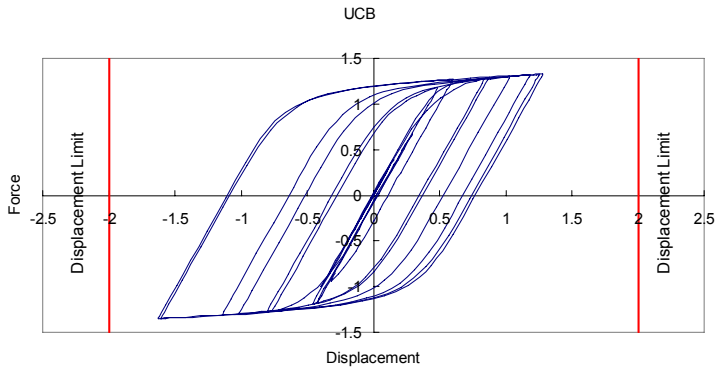


(c) MiniMOST 1 at UIUC

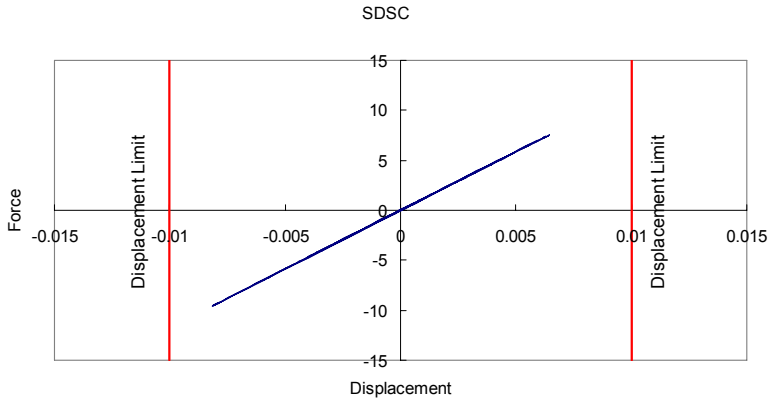
Figure 84 Hybrid test results – input case 2



(a) MiniMOST 1 at UIUC



(b) μNEES at UCB



(c) MiniMOST 1 at UIUC

Figure 85 Hybrid test results – input case 2

9.4.7 Experiment results

The three-site hybrid test among UIUC, UCB, and SDSC using recently enhanced UI-SIMCOR were conducted at October 6, 2006. Two steps were conducted to verify the communication and hybrid test.

Hybrid test by simulation (100 steps)

The main purpose of this step is to verify the communication among UIUC, UCB, and SDSC. The UI-SIMCOR communicates with control computer through LabVIEW plugin and LabVIEW plugin communicates with MiniMOST 1 through NTCP server as shown in Figure 86. The μNEES specimen at UCB communicates with xPC Real-time target PC through SCRAMNET and UI-SIMCOR communicates with xPC HOST PC through API as shown in Figure 58.

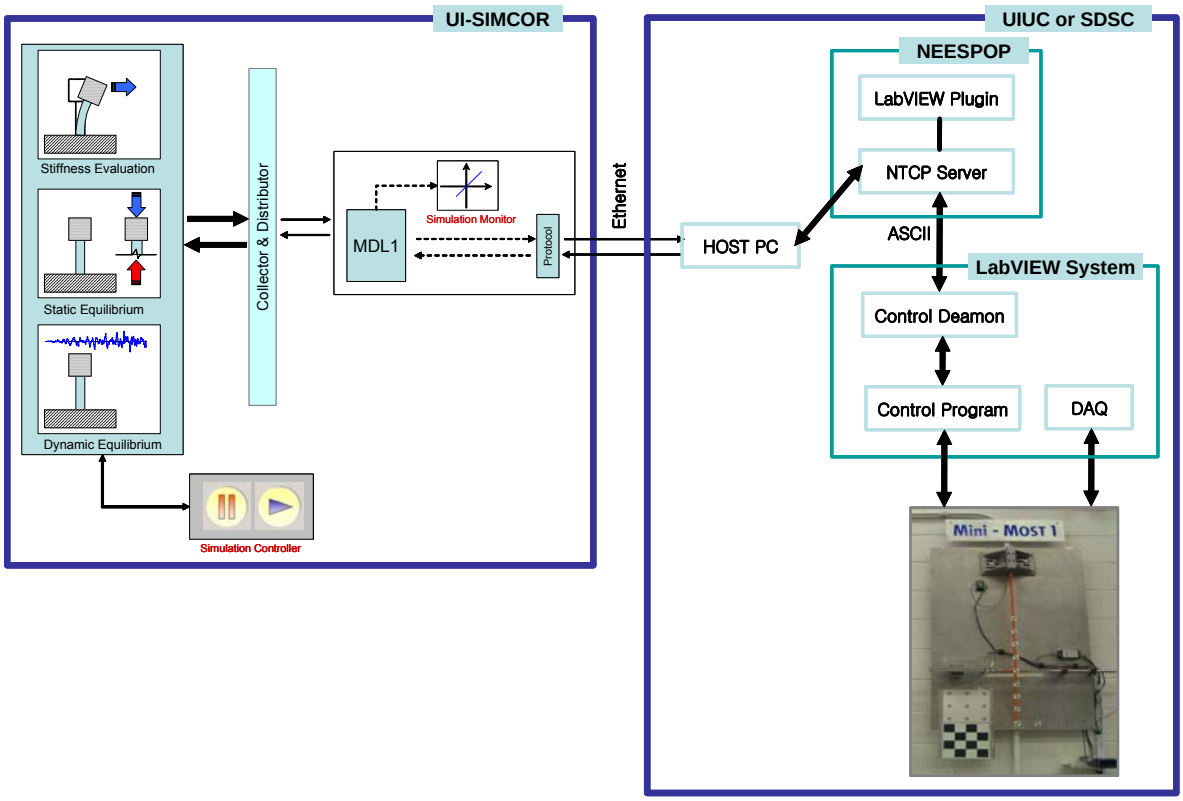


Figure 86 Configuration of HSF at UIUC or SDSC with UI-SIMCOR

Figures 87 ~89 show the simulation results. The "Expected" in figures means the results simulated in one computer whereas "Actual" means the results simulated with three-site, i.e., the UI-SIMCOR, MiniMOST 1 analytical model, and ZEUS-NL model were simulated at UIUC, μNEES analytical model was simulated at UCB, and MiniMOST 1 analytical model was simulated at SDSC.

It took 1 min and 29 sec for 100 steps (0.9 sec/per) to finish the pseudo dynamic analysis stage in UI-SIMCOR. As shown in figures, the results simulated at each site were exactly

matched with those simulated at one computer. Therefore, the communication among UIUC, UCB, and SDSC was verified through this test.

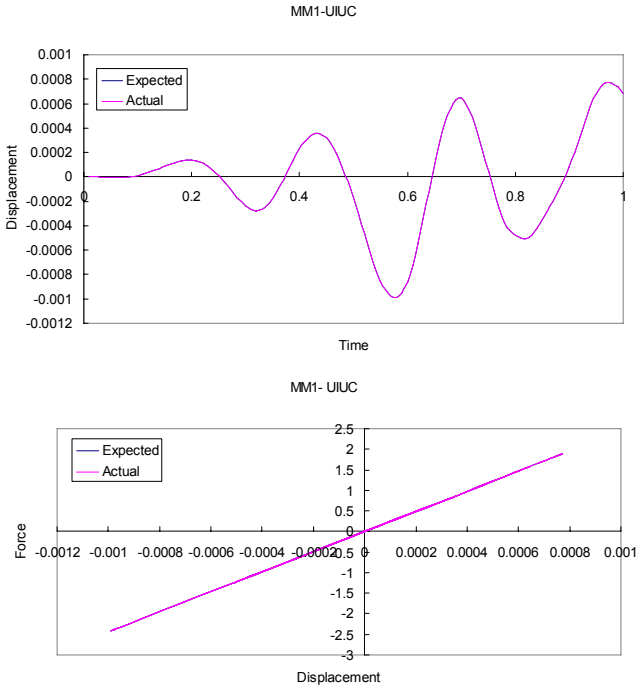


Figure 87 MiniMOST 1 at UIUC

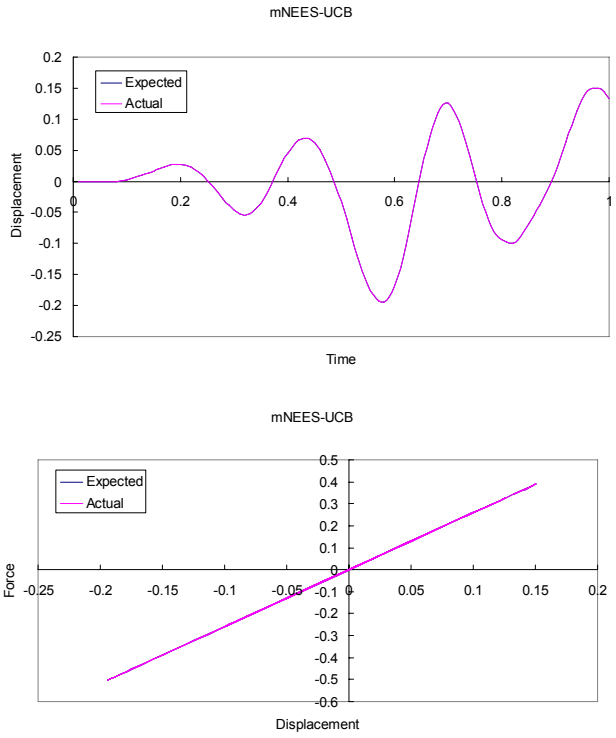


Figure 88 μNEES at UCB

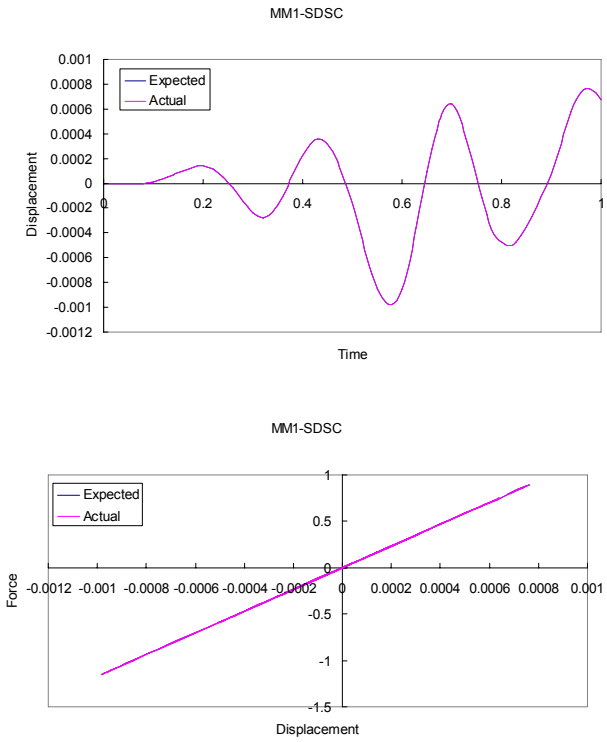


Figure 89 MiniMOST 1 at SDSC

Hybrid test by experiment (500 steps)

Figures 90 ~ 92 show the three-site hybrid test results. It took 54 min and 12 sec for 500 steps (6.5 sec/step) to finish the pseudo dynamic stage in UI-SIMCOR. For MiniMOST 1 at UIUC and SDSC consume few seconds to stabilize the load cell to get the good measurements. This is one of the reasons of the slow test.

During the test, following websites were used to see the status of each equipment through webcamera

For MiniMOST 1 at UIUC : http://cee-axs3.cee.uiuc.edu/view/indexFrame.shtml
For μNEES at UCB : http://neespopv.berkeley.edu/portal?section=local_video#
For MiniMOST 1 at SDSC : http://users.sdsc.edu/~ljmiller/side-tools/RDVmm.jnlp

As shown in figures, there are little difference between simulation and experiment especially at UCB site, because of difference of coupon at UCB specimen. The analytical model of μNEES specimen at UCB was obtained by using the pushover test results conducted during August 9, 2006 ~ August 16, 2006. Furthermore, the characteristic of specimen at UCB is highly dependent on the coupon installed in the specimen. The coupon used in this test is little bit different from the coupon used for pushover test, so there are little difference between simulation and experiment. This difference also affects

the other results at UIUC and SDSC because the example structure consists of four modules as shown in Figure 73.

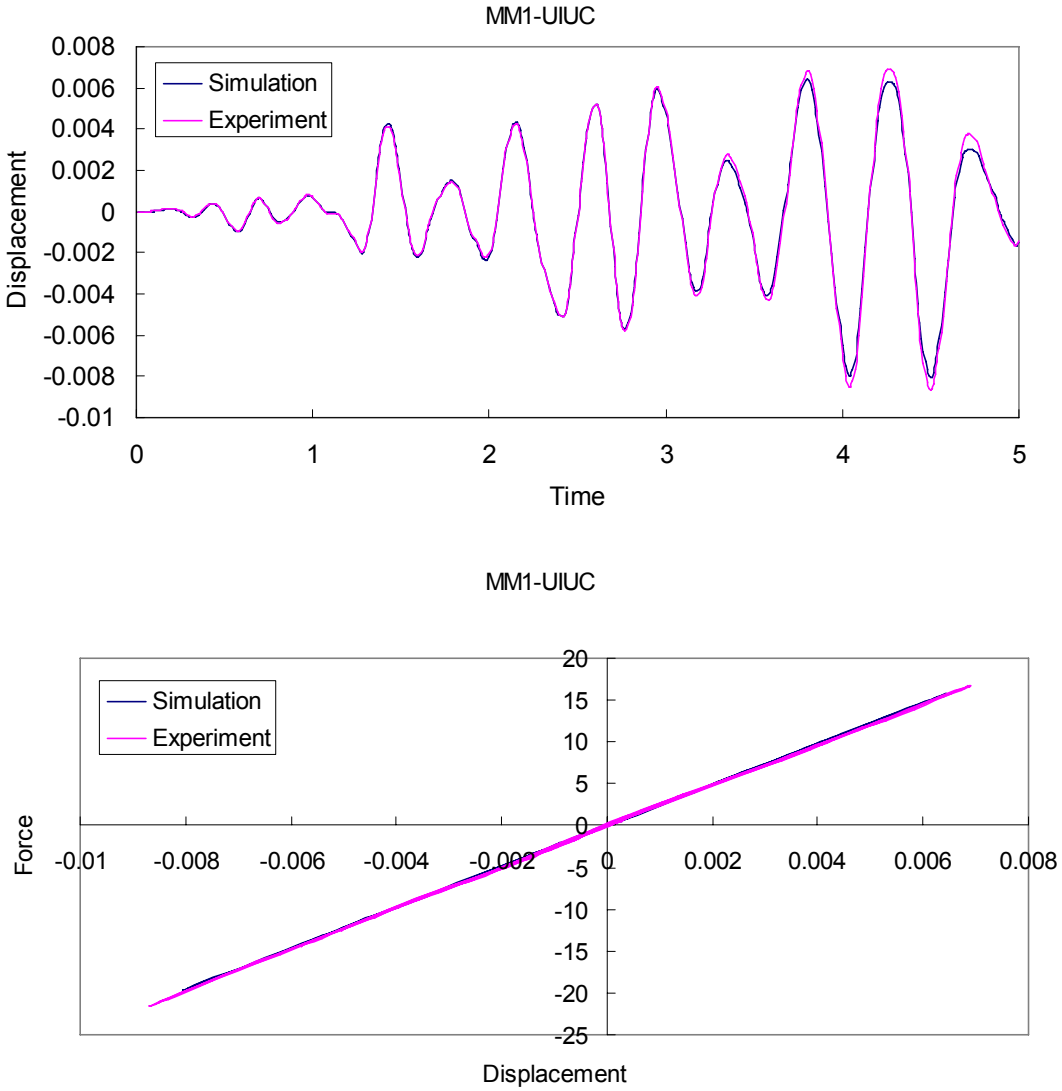


Figure 90 MiniMOST 1 at UIUC

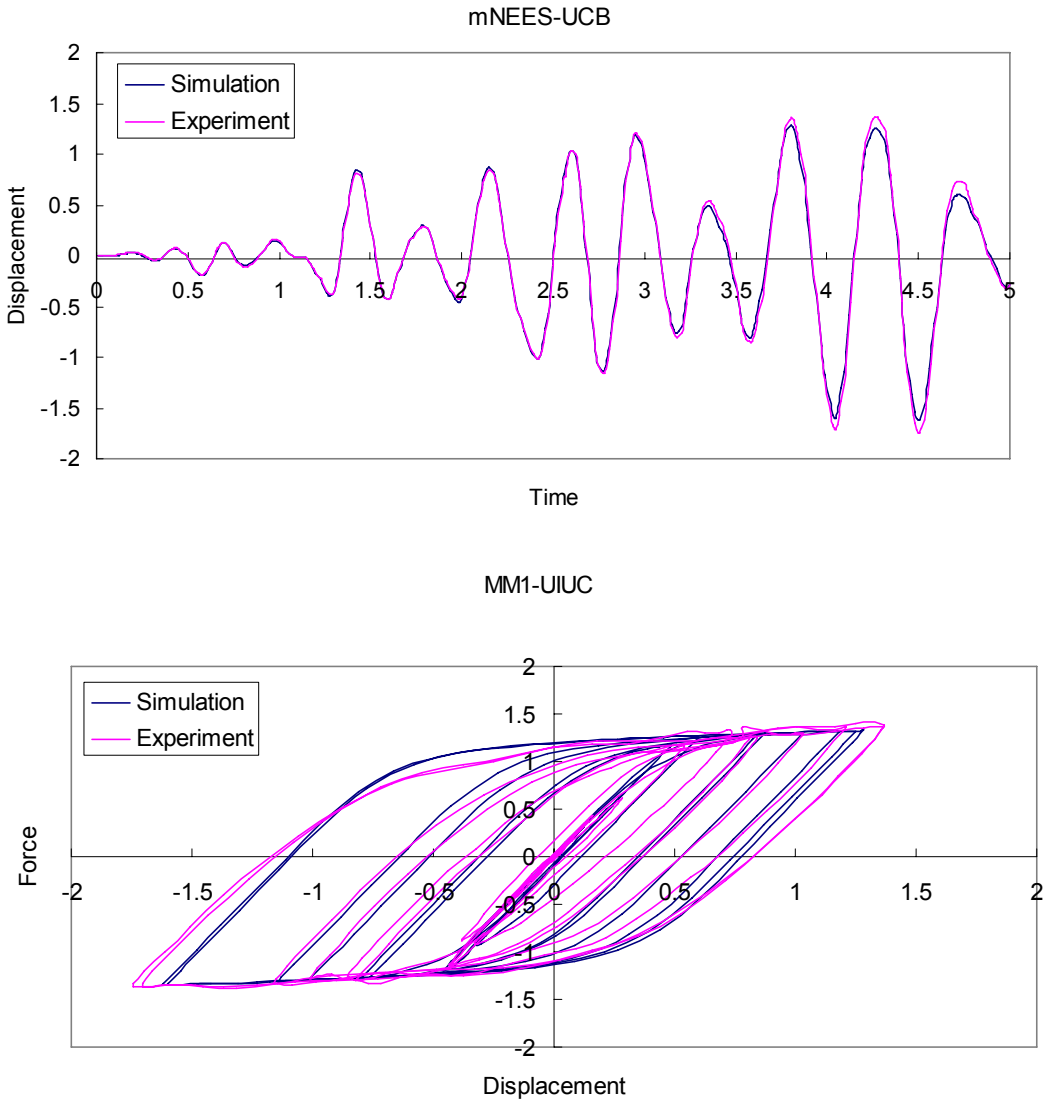


Figure 91 μNEES at UCB

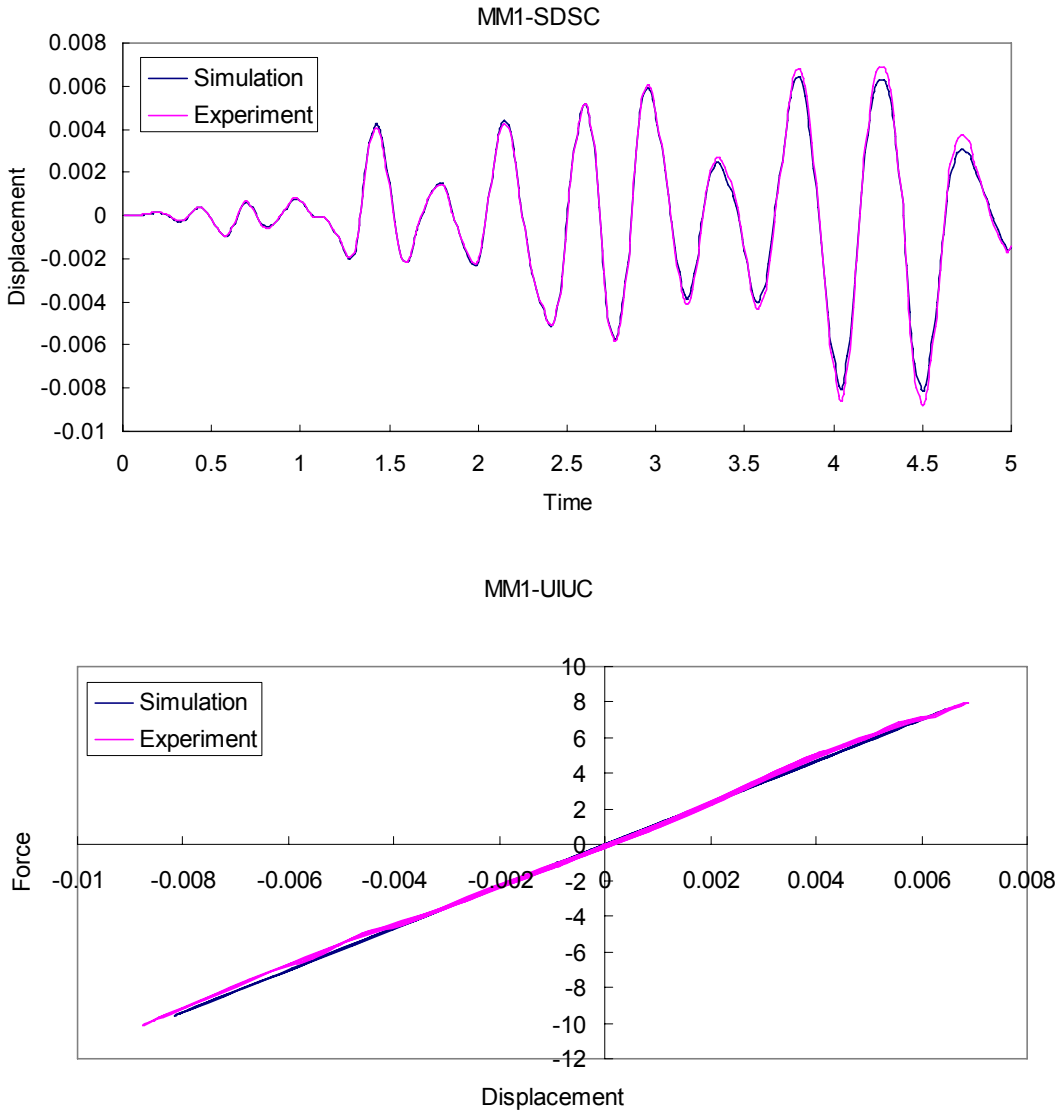


Figure 92 MiniMOST 1 at SDSC

9.4.8 Summary

The three-site hybrid test among UIUC, UCB, and SDSC was conducted to verify and demonstrate the efficacy of recently enhanced UI-SIMCOR. The MiniMOST 1 at UIUC and SDSC and μNEES at UCB were used in this test and the experimental results show good agreement with the simulation results. Therefore, UI-SIMCOR could be effectively used for hybrid test among geographically distributed equipments.

The three-site example in this report has only one DOF at each site, so it is required to use more DOFs during the hybrid test for more extensive verification of UI-SIMCOR.

For this purpose, the Loading and Boundary Condition Box (LBCB) which control 6 DOF will be considered for another three-site test in the near future.

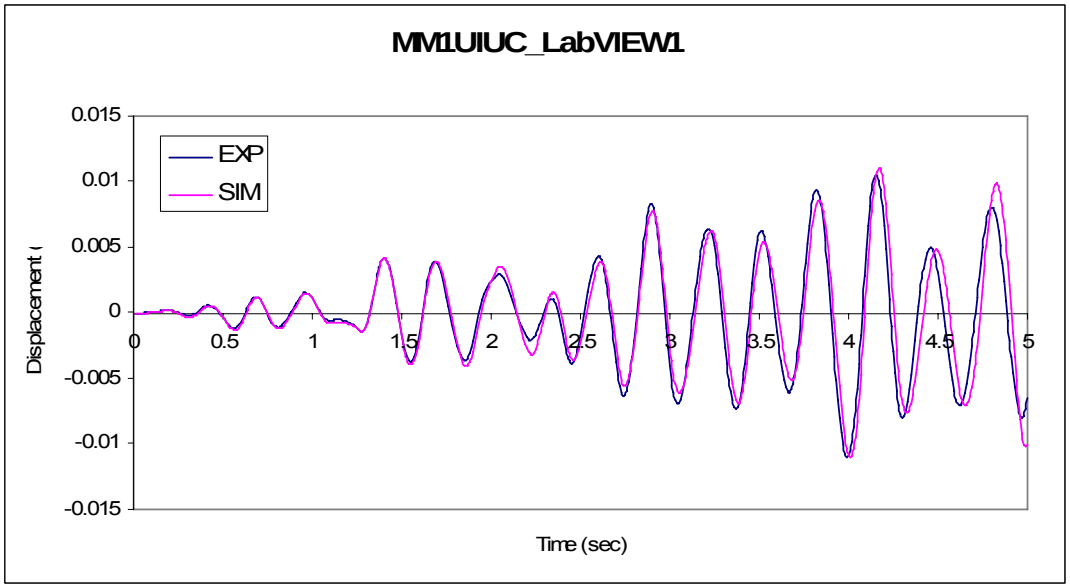
9.5 Two-site Experiment between UIUC and SDSC using NHCP

To verify the functionality of UI-SIMCOR with NHCP, geographically distributed hybrid simulation between UIUC and SDSC was conducted at January 29, 2007. The module 1 of MOST example structure explained Section 8.4 was replaced with MiniMOST 1 in UIUC using LabVIEW1 protocol, module 3 is replaced with MiniMOST in SDSC using NHCP, and module 2 is modeled by ZEUS-NL with LabVIEW2 protocol. However, the rotational DOF of module 1 is removed because MiniMOST 1 in UIUC has only one DOF in translational direction. The stiffness of MiniMOST 1 in UIUC and in SDSC can be found in the report of *Installation of UI-SIMCOR at SDSC and Implementation of NHCP in UI-SIMCOR* (Spencer, et al., 2006). So, the scale factor of each MiniMOST 1 can be obtained as follows.

Table 6. Scale factor of each MiniMOST 1

Site	Displacement	Rotation	Force	Moment
UIUC	0.711	1.000	0.484	1.000
SDSC	0.711	1.000	0.243	1.000

Figures 93 and 94 show the test results and it shows good agreement between experiment and simulation results. NEESit changed the signal conditioner of MiniMOST1 in SDSC to improve the load cell. It took around 1.25 sec/step (average during 500 steps) for MiniMOST1 in SDSC with new signal conditioner whereas it took around 2.89 sec/step for MiniMOST1 in UIUC. The signal conditioner of MiniMOST 1 in UIUC will be changed to improve the measuring time of load cell.



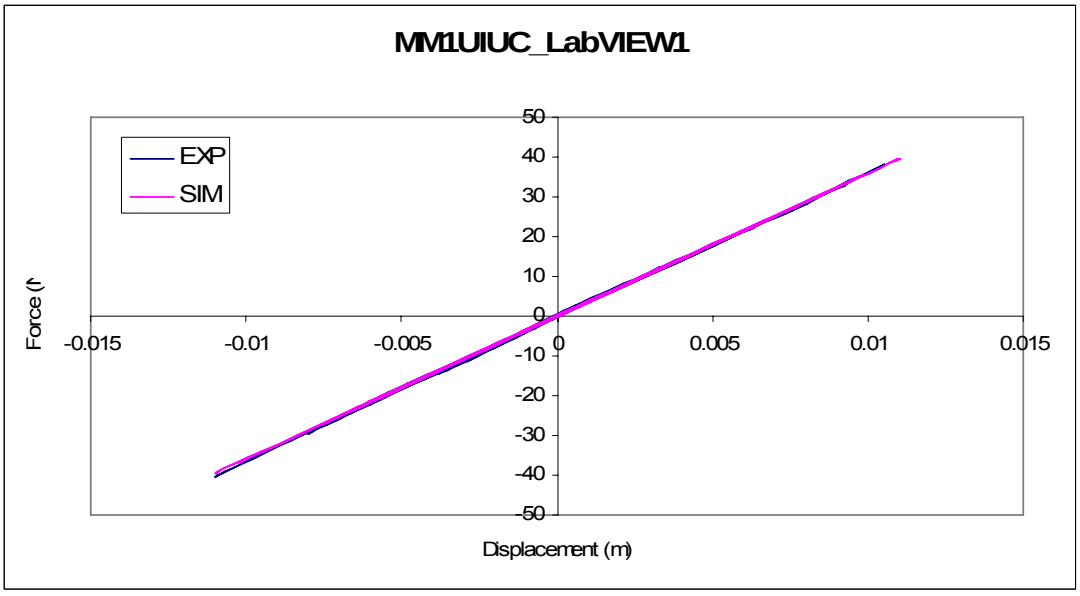
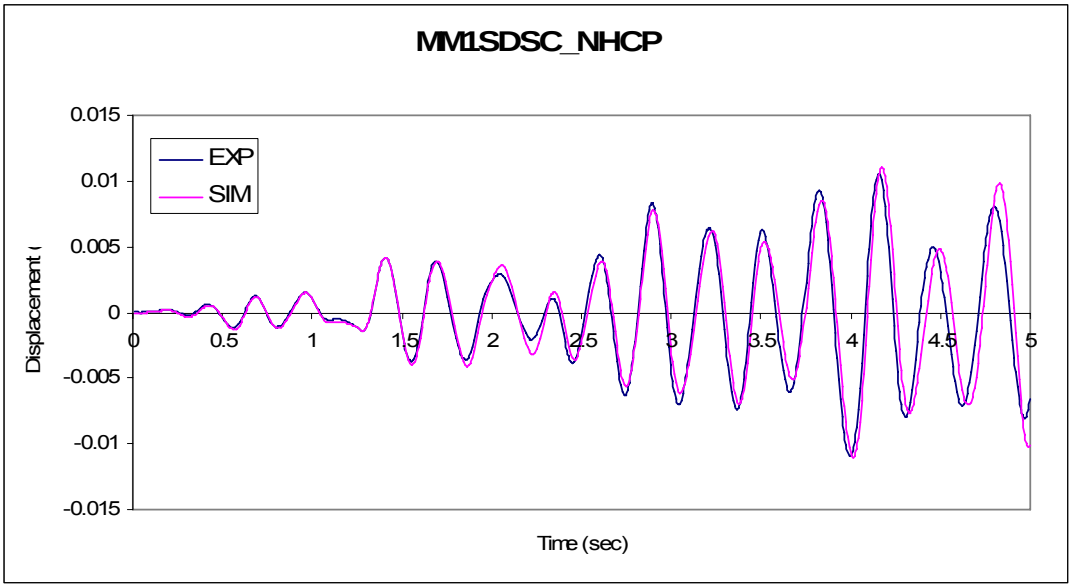


Figure 93 MiniMOST 1 at UIUC



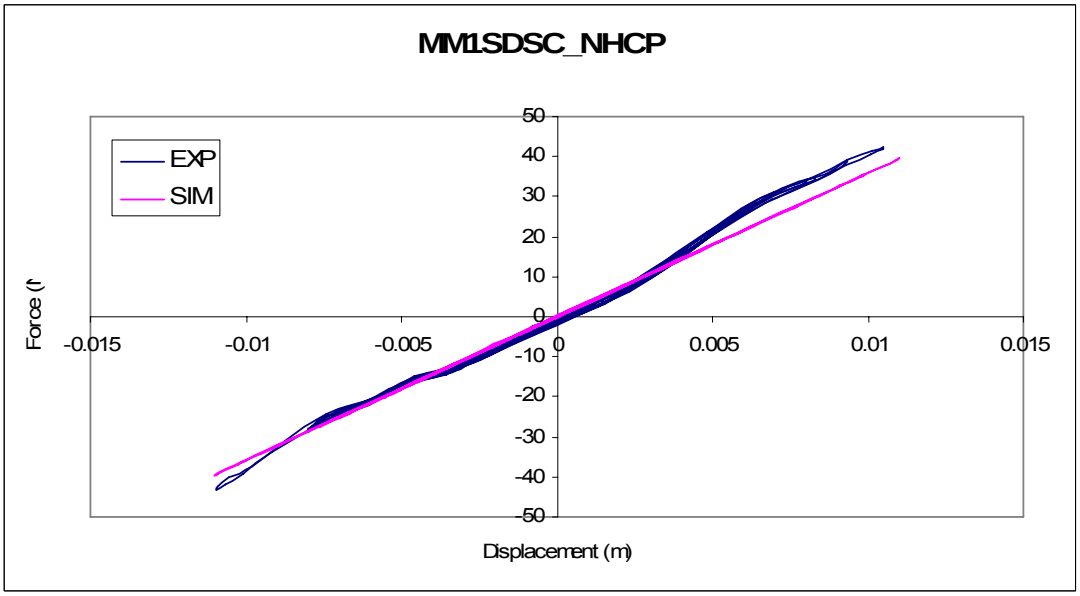


Figure 94 MiniMOST 1 in SDSC

10. References

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Elnashai, Amr S., Papanikolaou V., Lee, D. H. (2006). *User Manual for ZEUS-NL*. Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign.

Nakata, N., Spencer, B., Johoson, E. A., Elnashi, A. S., Kuchma, D. A. (2003). *Finite Element Modeling in MOST Simulation Code*. Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign.

Schellenberg, A, Kim, H., Takahashi Y., Fenves G. , Mahin S. (2006). "OpenFresco Framework for Hybrid Simulation: Installation and Example Guide.", Department of Civil and Environmental Engineering, University of California at Berkeley.

Schellenberg, A., Stojadinovic, B., Mahin, S. (2006). *The μNEES Hybrid Simulation Setup.* Department of Civil and Environmental Engineering, University of California at Berkeley.

Spencer, B. F., Jr., Elnashai, Amr, K. S. Park, O. S. Kwon (2006) *Installation of UI-SIMCOR at SDSC and Implementation of NHCP in UI-SIMCOR* Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign.

University of Illinois at Urbana-Champaign (2005) *User's Manual for MUST-SIM Facility*

Appendix: Experimental Procedure

A. Two-site Hybrid Test between UIUC and UCB

A-1 Step by step procedure for UIUC site

Stage	Step	To do	Purpose
Preliminary Stage	1	• Answer to questions	• Understand the experiment procedure
	2	• Confirm	• Backup the previous version of UI-SIMCOR, API_UCB, and example files
	3	• Confirm	• Uninstall previous version of UI-SIMCOR and delete all of previous files
	4	• Confirm	• Install new version of UI-SIMCOR and copy required files for UCB site
Simulation Stage	5	• Receive the results from UCB	• Verify the configuration of newly installed UI-SIMCOR
	6	• Check IP address and port number • Run the preliminary test by simulation in UCB (**API_Main_sim**) and UIUC (**UI_SimCor**) • Does UIUC site communicate with UCB site? • Is it running? • Receive the results from UCB • Backup the results	• Verify the communication between UIUC and UCB
Experiment Stage	7	• Is the current specimen similar to previous one? • Does the pushover test need?	• Check the properties of current specimen • If it needs, conduct the pushover test
	8	• Is it running? • Receive the results from UCB	• Verify the one-site experiment

	9	• Run the experiment in UCB (**API_Main**) and UIUC (**UI_SimCor**) • Is it running? • Receive the results from UCB • Backup the results	• Verify the hybrid test between UIUC and UCB
Post-experiment Stage	**10**	• Make analytical model based on the pushover test results • Compare the experimental results with analytical ones • Customize documentation • Send documents to UCB • Answer to questions	• Verify the results

A-2 Step by step procedure for UCB site

Stage	Step	To do
Preliminary Stage	**1**	• Print this document (UCB_Report.doc) • Read document very carefully, especially 5. Hybrid test between UIUC and UCB • Is there any questions?
	2	• Backup C:\SIMCOR folder
	3	• Uninstall UI-SIMCOR and delete C:\SIMCOR folder
	4	• Install new version of UI-SIMCOR • Copy 05_API_UCB and 06_Examples_UCB folder to C:\SIMCOR\ • Add paths in MATLAB
Simulation Stage	**5**	• Run the preliminary test by simulation (**API_Main_sim** and **UI_SimCor**) in UCB site only • Is it running? • Backup the results and send to UIUC
	6	• Give IP address and port number to UIUC • Run the preliminary test by simulation in UCB (**API_Main_sim**) and UIUC (**UI_SimCor**) • Does UCB site communicate with UIUC site? • Is it running? • Backup the results and send to UIUC
Experiment Stage	**7**	• Answer to questions • If it needs, conduct pushover test
	8	• Run the experiment in UCB only (**API_Main** and **UI_SimCor**) • Is it running? • Back up the results and send to UIUC

	9	• Run the experiment in UCB (**API_Main**) and UIUC (**UI_SimCor**) • Is it running? • Backup the results and send to UIUC
Post-experiment Stage	**10**	• Receive the results document from UIUC later • Is there any questions?

A-3. Detailed procedure of each step

Installation procedure

Installation of UI-SIMCOR

Before install the UI-SIMCOR, backup C:\SIMCOR folder and remove previous version of UI-SIMCOR (*Start-Set Program Access and Defaults-Change or Remove Programs*, then select UI-SIMCOR and *Remove*) and delete C:\SIMCOR folder

By double clicking the distributed installation file (**SimCor.msi**), you can install UI-SIMCOR, NEES-SAM and example files. **When install software, DO NOT change the default folder location. The software should be installed in C:\SIMCOR.**

After install the UI-SIMCOR, copy separately distributed files, 05_API_UCB and 06_Examples_UCB to C:\SIMCOR\ folder. These folders include the API and example files for UCB site.

Finally, add the following paths in MATLAB. To do that, open MATLAB and click *File-Set Path*. Following folders should be in the path of MATLAB.

Paths for UI-SIMCOR

C:\SIMCOR\01_SIMCOR
C:\SIMCOR\01_SIMCOR\parmatlab

Paths for UCB site: This is necessary only for UCB site. Scripts in the folder 04_API\01_UCB are written to operate xPC Real-time trarget in UCB site.

C:\SIMCOR\04_API\01_UCB

Paths for FEDEAS Lab: This is necessary only for when FEDEAS Lab. is used to model part of a structure.

C:\SIMCOR\02_NEES-FL
C:\SIMCOR\02_NEES-FL\FedeasLab
C:\SIMCOR\02_NEES-FL\FedeasLab\Element_Lib
C:\SIMCOR\02_NEES-FL\FedeasLab\General
C:\SIMCOR\02_NEES-FL\FedeasLab\Geometry
C:\SIMCOR\02_NEES-FL\FedeasLab\Material_Lib

C:\SIMCOR\02_NEES-FL\FedeasLab\Output
C:\SIMCOR\02_NEES-FL\FedeasLab\Section_Lib
C:\SIMCOR\02_NEES-FL\FedeasLab\Solution_Lib
C:\SIMCOR\02_NEES-FL\FedeasLab\Utilities

Path for ABAQUS

C:\SIMCOR\02_NEES-ABAQUS

For simple procedure

1. Run a MATLAB
2. click *File-Set Path-Add with Subfolders* in the menu bar
   - Select C:\SIMCOR\01_SIMCOR and click the **OK** button
3. Repeat step 2 for C:\SIMCOR\02_NEES-FL, C:\SIMCOR\02_NEES-ABAQUS, and C:\SIMCOR\04_API\01_UCB.
4. Click **Save** button to save the paths
5. Click **Close** button

Step 5

Run the preliminary test by simulation (**API_Main_sim** and **UI_SimCor**) in UCB site only

Purpose: Verify the configuration of newly installed UI-SIMCOR

The default value of the displacement limit is 6. If the target displacement which will be sent to xPC Real-time target is greater than the displacement limit, then the simulation will be stopped with error message. If you want to modify the displacement limit, open the **API_Main_sim** and modify Disp_Limit variable at line 17.

1. Run a MATLAB for UI-SIMCOR and change the directory to C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
2. Type **UI_SimCor** and enter in MALAB command window to run UI-SIMCOR

New simulation
Please backup previous simulation results if necessary. All previous files will be deleted.
Okay
Cancel

Figure A-1 Warning message

a. Click **Okay** button, you will see the initialize message in a MATLAB command window. All previous files will be deleted, so if necessary backup previous results.
b. Two popup windows will be displayed, one window for control and other

window for monitoring will popup. In this example, only one monitoring window will be displayed as this example has only one remote site.

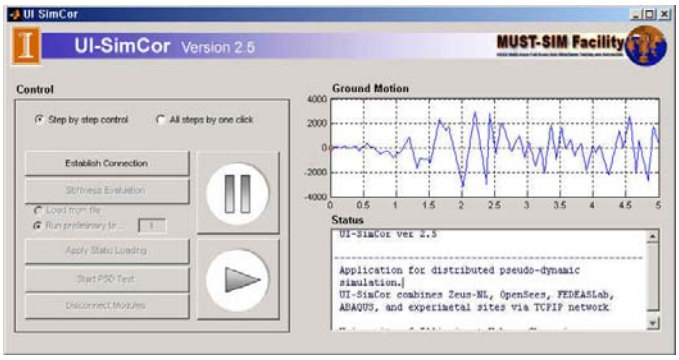


Figure A-2 Control window

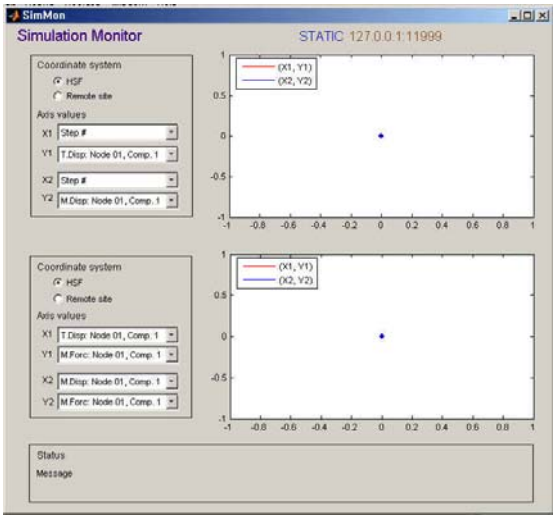


Figure A-3 Monitoring window

3. Run another MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
4. Type **API_Main_sim**, then you will see the message box confirming the displacement limit as shown in Figure A-4.

Check Displacement Limit
Current displacement limit for UCB speicmen: 6.00e+000
If you want modify the displacement limit, please open API_Main_sim.m
Okay
Reset

Figure A-4 Warning message for the displacement limit

a. If the displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 11999 …" in a MATLAB command window. The IP address and port number are dependent on experimental configuration.

b. If you want modify the displacement limit, click **Reset** button, then the **API_Main_sim** file is opened automatically. Modify the Disp_Limit variable at line 17.

Now ready to run the test by simulation

5. Click **Establish Connection** button in UI-SIMCOR control window. You will see some messages indicating that the connection is established in both MALTAB command windows and another simulation monitor of GUI for UCB site will be displayed in the MATLAB for **API_Main_sim** as shown in Figure A-5.

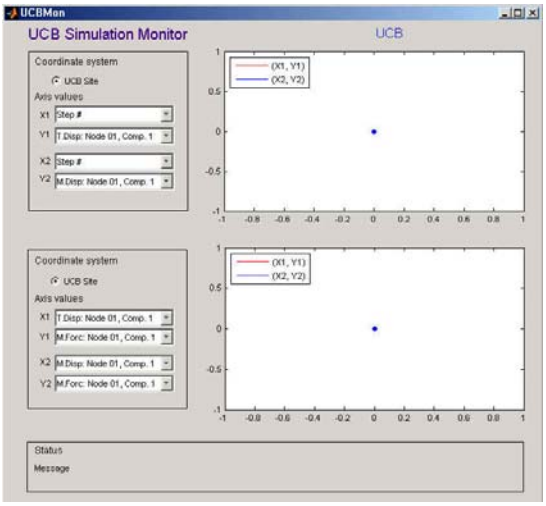


Figure A-5 Monitoring window for UCB site

a. If the UI-SIMCOR run in the other computer or the other site (i.e., UIUC), then this GUI helps to UCB site seeing current status of experiment.

6. Click **Stiffness Evaluation** button in UI-SIMCOR control window. UI-SIMCOR will read the predefined stiffness matrix from file (MDL01_K.txt) located in C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
7. Click **Apply Static Loading** button in UI-SIMCOR control window. In this stage, the gravity force is applied, however, there is no plan to apply gravity as this exemplary test is to demonstrate the efficacy of hybrid simulation framwork.
8. Click **Start PSD Test** to run test **by simulation**. The target displacement and feedback displacement and force will be displayed in the monitoring window and UCB monitoring window.
9. Click **Disconnect Modules** after finishing hybrid simulation to disconnect UI-SIMCOR from xPC Real-time target. You will see some messages indicating the communication is disconnected in both MALTAB command windows.
10. Backup the results files (MDL01_recv.txt, Netwklog.txt, NodeDisp.txt) located in C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator and another results files (NetwkLog.txt, UCB_Results.txt) located in C:\SIMCOR\04_API\01_UCB
11. Send results to UIUC

Step 6

Run the preliminary test by simulation in UCB (**API_Main_sim**) and in UIUC (**UI_SimCor**)

Purpose: Verify the communication between UIUC and UCB

Most of procedure is same with **Step 5** except the UI-SIMCOR will run in UIUC site.
To do this test, UIUC should know the IP address and port number of UCB site.

The default value of the displacement limit is 6. If the target displacement which will be sent to xPC Real-time target is greater than the displacement limit, then the simulation will be stopped with error message. If you want to modify the displacement limit, open the **API_Main_sim** and modify Disp_Limit variable at line 17.

UIUC Site

1. Run a MATLAB for UI-SIMCOR and change the directory to C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
2. Type **UI_SimCor** and enter in MALAB command window to run UI-SIMCOR

New simulation
Please backup previous simulation results if necessary. All previous files will be deleted.
Okay
Cancel

Figure A-6 Warning message

a. Click **Okay** button, you will see the initialize message in a MATLAB command window. All previous files will be deleted, so if necessary backup previous results.
b. Two popup windows will be displayed, one window for control and other window for monitoring will popup. In this example, only one monitoring window will be displayed as this example has only one remote site.

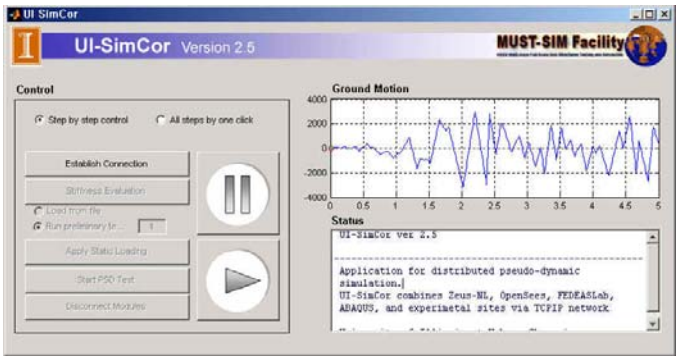


Figure A-7 Control window

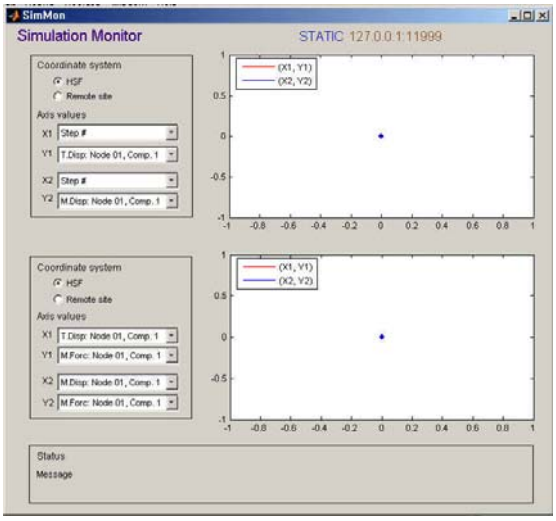


Figure A-8 Monitoring window

UCB Site

3. Run another MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
4. Type **API_Main_sim**, you will see the message box confirming the displacement limit as shown in Figure A-9.

Check Displacement Limit
Current displacement limit for UCB speicmen: 6.00e+000
If you want modify the displacement limit, please open API_Main_sim.m
Okay
Reset

Figure A-9 Warning message for the displacement limit

a. If the displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 11999 …" in a MATLAB command window.
b. If you want modify the displacement limit, click **Reset** button, then the **API_Main_sim** file is opened automatically. Modify the Disp_Limit variable at line 17.

Now ready to run the test by simulation

UIUC Site

5. Click **Establish Connection** button in UI-SIMCOR control window. You will see some messages indicating that the connection is established in both MALTAB command windows and another simulation monitor of GUI for UCB site will be displayed in the MATLAB for **API_Main_sim** (UCB site) as shown in Figure A-10.

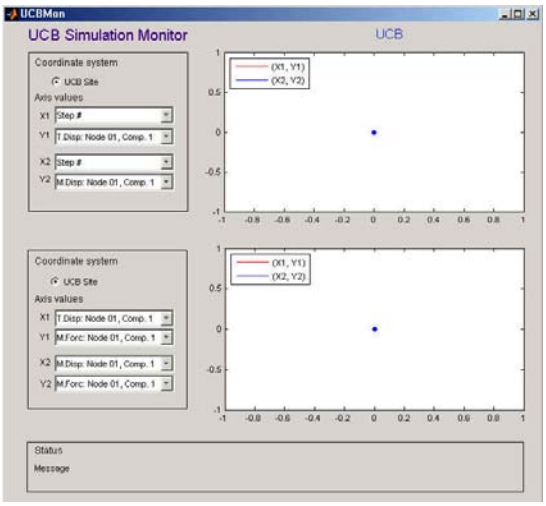


Figure A-10 Monitoring window for UCB site

   a. If the UI-SIMCOR run in the other computer or the other site (i.e., UIUC), then this GUI helps to UCB site seeing current status of experiment.
6. Click **Stiffness Evaluation** button in UI-SIMCOR control window. UI-SIMCOR will read the predefined stiffness matrix from file (MDL01_K.txt) located in C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
7. Click **Apply Static Loading** button in UI-SIMCOR control window. In this stage, the gravity force is applied, however, there is no plan to apply gravity as this exemplary test is to demonstrate the efficacy of hybrid simulation framework.
8. Click **Start PSD Test** to run test by simulation. The target displacement and feedback displacement and force will be displayed in the monitoring window and UCB monitoring window.
9. Click **Disconnect Modules** after finishing hybrid simulation to disconnect UI-SIMCOR from xPC Real-time target. You will see some messages indicating the communication is disconnected in both MALTAB command windows.
10. Backup the results files (MDL01_recv.txt, Netwklog.txt, NodeDisp.txt) located in C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator **for UIUC site** and another results files (NetwkLog.txt, UCB_Results.txt) located in C:\SIMCOR\04_API\01_UCB **for UCB site**
11. Send results to UIUC

Step 7

Pushover test for UCB specimen

Purpose: To calculate the scale factor for UI-SIMCOR and to make analytical model for comparison

Most of procedure is same with **Step 5** except the running **PushOver** instead of **UI_SimCor**.

The default value of the displacement limit is 6. If the target displacement which will be sent to xPC Real-time target is greater than the displacement limit, then the simulation will be stopped with error message. If you want to modify the displacement limit, open the **API_Main_sim** (for simulation) or **API_Main** (for experiment) and modify Disp_Limit variable at line 17.

1. Run a MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
2. Type **API_Main_sim** (for simulation) or **API_Main** (for experiment), then you will see the message box confirming the displacement limit as shown Figure A-11.

Check Displacement Limit
Current displacement limit for UCB speicmen: 6.00e+000
If you want modify the displacement limit, please open API_Main_sim.m
Okay
Reset

Figure A-11 Warning message

   a. If displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 11999 …" in a MATLAB command window.
   b. If you want modify the displacement limit, click **Reset** button, then the **API_Main_sim** (for simulation) or **API_Main** (for experiment) file is opened automatically. Modify the Disp_Limit variable at line 17.

Now ready to run the pushover test – This test will run automatically

3. Run another MATLAB for the pushover test and change the directory to C:\SIMCOR\03_Examples\UCB\PushoverTest\00_Coordinator
4. Type **PushOver** and enter in MALAB command window to run the pushover test
   a. This is running automatically.
   b. Another simulation monitor of GUI as shown in Figure A-12 for UCB site will be displayed in the MATLAB for **API_Main_sim** (for simulation) or **API_Main** (for experiment).

c. **The default value of maximum displacement for Pushover Test is 2**. If you want to modify the maximum value, please open the **PushOver** and modify the disp_scale variable at line 66.

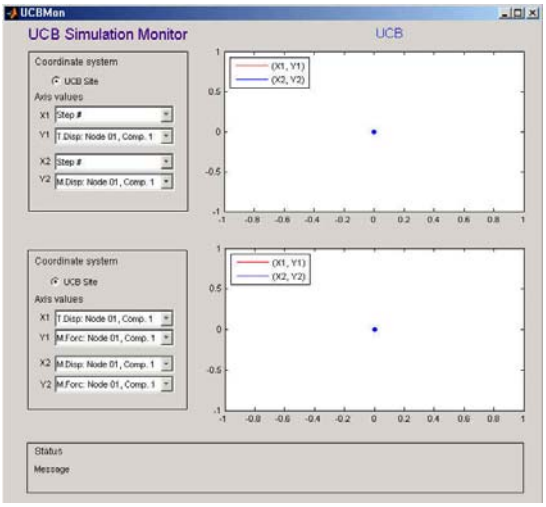


Figure A-12 Monitoring window for UCB site

5. Backup the results files (MDL00_recv.txt, Netwklog.txt) located in C:\SIMCOR\03_Examples\UCB\PushoverTest\00_Coordinator and another results files (NetwkLog.txt, UCB_Results.txt) located in C:\SIMCOR\04_API\01_UCB
6. Send results to UIUC

Step 8

Run the experiment in UCB only (**API_Main** and **UI_SimCor**)

Purpose: Verify the one-site hybrid simulation

Most of procedure is same with **Step 5** except the running **API_Main** instead of **API_Main_sim**.

The default value of the displacement limit is 6. If the target displacement which will be sent to xPC Real-time target is greater than the displacement limit, then the simulation will be stopped with error message. If you want to modify the displacement limit, open the **API_Main** and modify Disp_Limit variable at line 17.

1. Run a MATLAB for UI-SIMCOR and change the directory to C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
2. Type **UI_SimCor** and enter in MALAB command window to run UI-SIMCOR

New simulation
Please backup previous simulation results if necessary. All previous files will be deleted.
Okay
Cancel

Figure A-13 Warning message

a. Click **Okay** button, you will see the initialize message in a MATLAB command window. All previous files will be deleted, so if necessary backup previous results.
b. Two popup windows will be displayed; one window for control and other window for monitoring will popup. In this example, only one monitoring window will be displayed as this example has only one remote site.

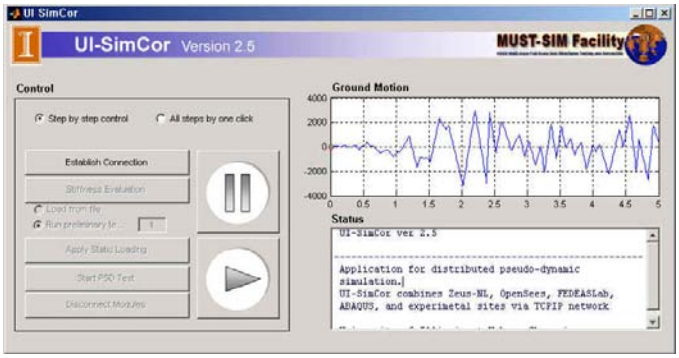


Figure A-14 Control window

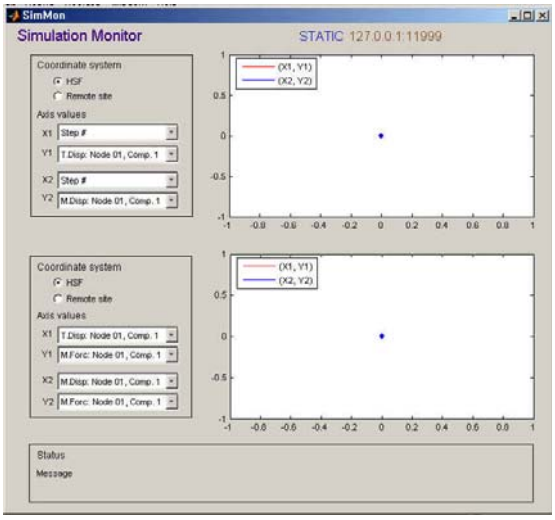


Figure A-15 Monitoring window

3. Run another MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
4. Type **API_Main**, you will see the message box confirming the displacement limit as shown in Figure A-16.

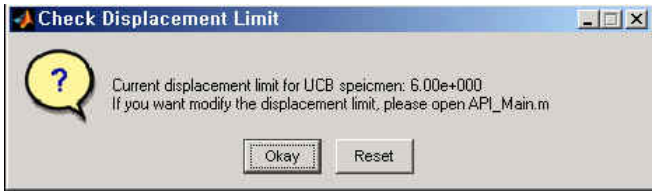

Check Displacement Limit
Current displacement limit for UCB speicmen: 6.00e+000
If you want modify the displacement limit, please open API_Main.m
Okay
Reset

Figure A-16 Warning message

a. If the displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 11999 …" in a MATLAB command window.
b. If you want modify the displacement limit, click **Reset** button, then the **API_Main** file is opened automatically. Modify the Disp_Limit variable at line 17.

Now ready to run experiment!! – real experiment

5. Click **Establish Connection** button in UI-SIMCOR control window. You will see some messages indicating that the connection is established in both MALTAB command windows and another simulation monitor of GUI for UCB site will be displayed in the MATLAB for **API_Main** as shown in Figure A-17.

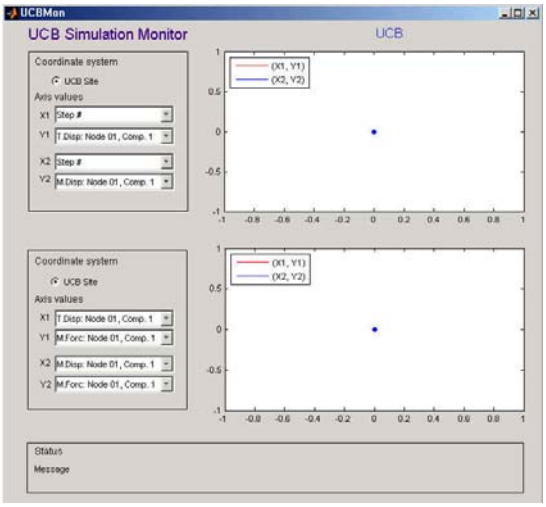


Figure A-17 Monitoring window for UCB site

a. If the UI-SIMCOR run in the other computer or the other site (i.e., UIUC), then this GUI helps to UCB site seeing current status of experiment.
6. Click **Stiffness Evaluation** button in UI-SIMCOR control window. UI-SIMCOR will read the predefined stiffness matrix from file (MDL01_K.txt) located in C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
7. Click **Apply Static Loading** button in UI-SIMCOR control window. In this stage, the gravity force is applied, however, there is no plan to apply gravity as this exemplary test is to demonstrate the efficacy of hybrid simulation framework.
8. Click **Start PSD Test** to run test by experiment. The target displacement and feedback displacement and force will be displayed in the monitoring window and

UCB monitoring window.

9. Click **Disconnect Modules** after finishing hybrid simulation to disconnect UI-SIMCOR from xPC Real-time target. You will see some messages indicating the communication is disconnected in both MALTAB command windows.
10. Backup the results files (MDL01_recv.txt, Netwklog.txt, NodeDisp.txt) located in C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator and another results files (NetwkLog.txt, UCB_Results.txt) located in C:\SIMCOR\04_API\01_UCB
11. Send results to UIUC

Step 9

Run the experiment in UCB (**API_Main**) and in UIUC (**UI_SimCor**)

Purpose: Verify the hybrid simulation between UIUC and UCB

Most of procedure is same with **Step 8** except the UI-SIMCOR will run in UIUC site.
To do this test, UIUC should know the IP address and port number of UCB site.

The default value of the displacement limit is 6. If the target displacement which will be sent to xPC Real-time target is greater than the displacement limit, then the simulation will be stopped with error message. If you want to modify the displacement limit, open the **API_Main** and modify Disp_Limit variable at line 17.

UIUC Site

1. Run a MATLAB for UI-SIMCOR and change the directory to C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
2. Type **UI_SimCor** and enter in MALAB command window to run UI-SIMCOR

New simulation
Please backup previous simulation results if necessary. All previous files will be deleted.
Okay
Cancel

Figure A-18 Warning message

a. Click **Okay** button, then you will see the initialize message in a MATLAB command window. All previous files will be deleted, so if necessary backup previous results.
b. Two popup windows will be displayed, one window for control and other window for monitoring will popup. In this example, only one monitoring window will be displayed as this example has only one remote site.

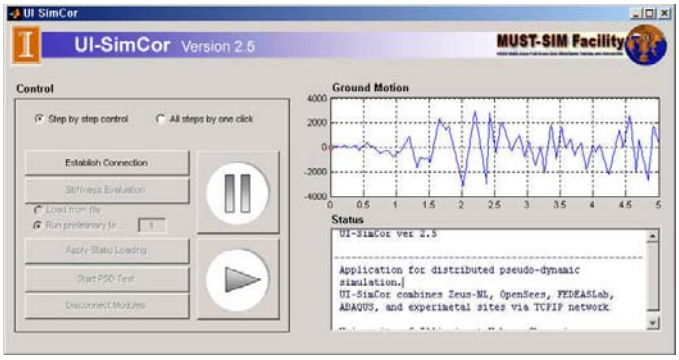


Figure A-19 Control window

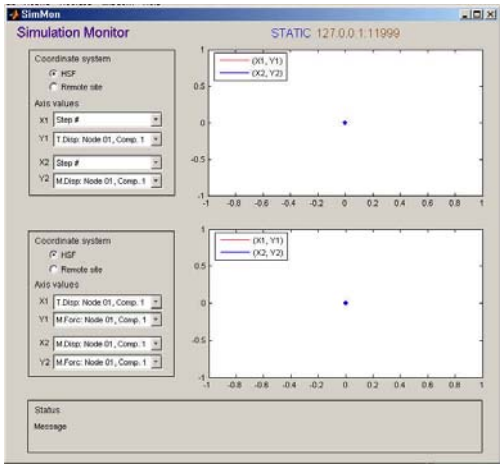


Figure A-20 Monitoring window

UCB Site

3. Run another MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
4. Type **API_Main**, then you will see the message box confirming the displacement limit as shown in Figure A-21.

Check Displacement Limit
Current displacement limit for UCB speicmen: 6.00e+000
If you want modify the displacement limit, please open API_Main_sim.m
Okay
Reset

Figure A-21 Warning message for the displacement limit

a. If the displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 11999 …" in a MATLAB command window.
b. If you want modify the displacement limit, click **Reset** button, then the **API_Main** file is opened automatically. Modify the Disp_Limit variable at line 17.

Now ready to run the test by simulation

UIUC Site

5. Click **Establish Connection** button in UI-SIMCOR control window. You will see some messages indicating that the connection is established in both MALTAB command windows and another simulation monitor of GUI for UCB site will be displayed in the MATLAB for **API_Main** as shown in Figure A-22.

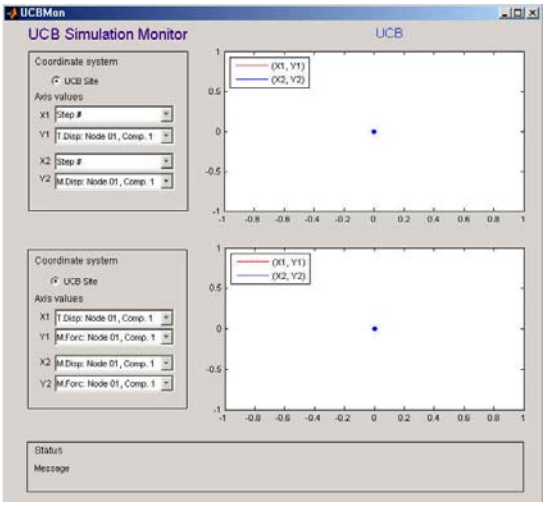


Figure A-22. Monitoring window for UCB site

   a. If the UI-SIMCOR run in the other computer or the other site (i.e., UIUC), then this GUI helps to UCB site seeing current status of experiment.
6. Click **Stiffness Evaluation** button in UI-SIMCOR control window. UI-SIMCOR will read the predefined stiffness matrix from file (MDL01_K.txt) located in C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator
7. Click **Apply Static Loading** button in UI-SIMCOR control window. In this stage, the gravity force is applied, however, there is no plan to apply gravity as this exemplary test is to demonstrate the efficacy of hybrid simulation framework.
8. Click **Start PSD Test** to run test by experiment. The target displacement and feedback displacement and force will be displayed in the monitoring window and UCB monitoring window.
9. Click **Disconnect Modules** after finishing hybrid simulation to disconnect UI-SIMCOR from xPC Real-time target. You will see some messages indicating the communication is disconnected in both MALTAB command windows.
10. Backup the results files (MDL01_recv.txt, Netwklog.txt, NodeDisp.txt) located in C:\SIMCOR\03_Examples\UCB\SDOF\00_Coordinator **for UIUC site** and another results files (NetwkLog.txt, UCB_Results.txt) located in C:\SIMCOR\04_API\01_UCB **for UCB site**
11. Send results to UIUC

B. Three-site Hybrid Test among UIUC, UCB and SDSC

The detailed experiment procedure for real three-site hybrid test is introduced in this section. All the three sites (UIUC, UCB, and SDSC) should understand the whole procedure for the successful completion of the experiment.

The experiment procedure consists of two steps. Step 1 is to verify the communication among UIUC, UCB, and SDSC by conducting a numerical hybrid simulation. Step 2 is to conduct the real three-site hybrid test using the actual experimental components. Each step is divided in *(a) Prepare the communication among UIUC, UCB, and SDSC*, *(b) Prepare the UI-SIMCOR for hybrid simulation*, and *(c) Conduct the hybrid test*.

B-1 Step 1: Hybrid test by simulation (100 steps)

This is simulation, so it will not send any signal to actuator.

The purpose of this step is to verify the communication among UIUC, UCB, and SDSC through running the three-site example by simulation. **UI-SIMCOR**, **MiniMOST 1 analytical model**, and **ZEUS-NL model** (UIUC), **μNEES analytical model** (UCB), and **MiniMOST 1 analytical model** (SDSC) will be simulated.

For this test, following IP address and port number of each site will be used.

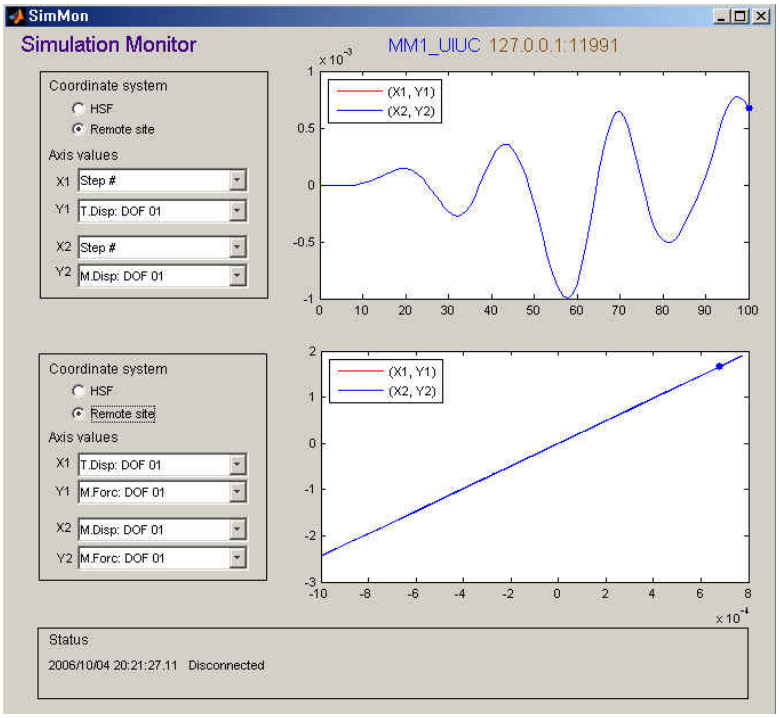
For MM1 at UIUC : 130.126.240.138:44000
For μNEES at UCB : 169.229.203.152:8090
For MM1 at SDSC : 137.110.118.95:44000

Table B-1 Displacement limit of each site

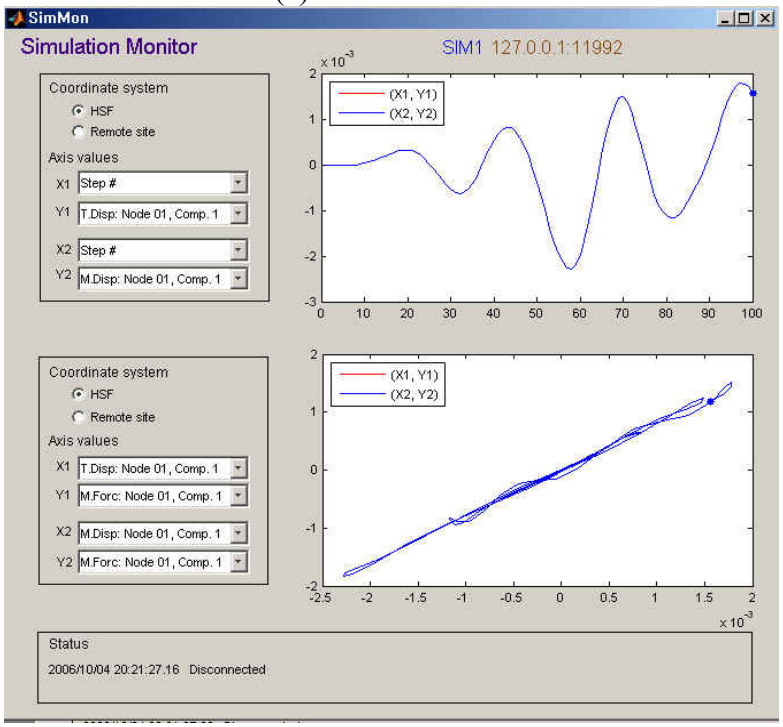
UIUC	UCB	SDSC
0.01	2.0	0.01

The displacement limit of each site for this experiment is shown in Table B-1. However, the actual displacement limit of each site is larger than theses values. For this test, the displacement limit of each site is assumed smaller than actual one for safety issue. If the target displacement which will be sent to each actuator is greater than the displacement limit of each site, the test will be paused with warning message.

The expected results of this test are shown in following figures.

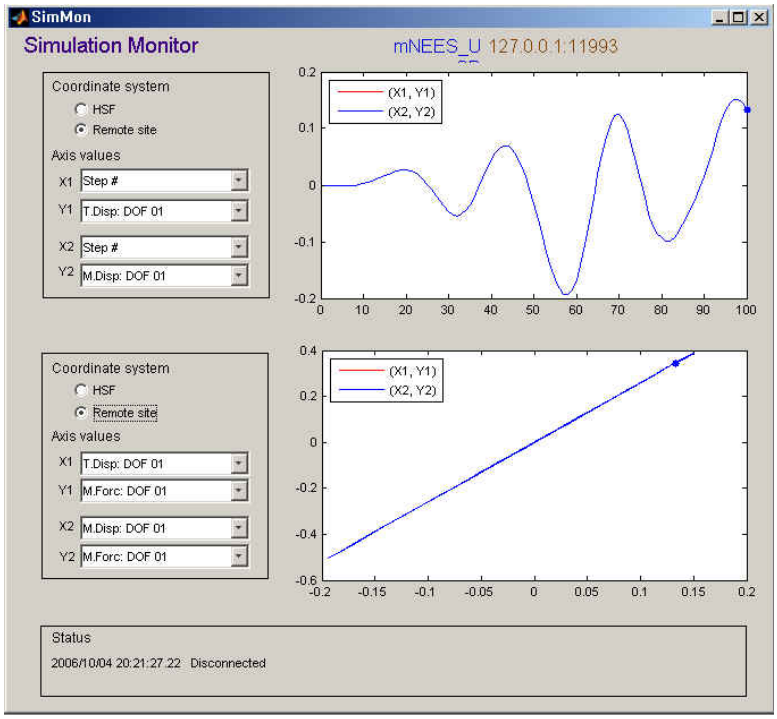


(a) MM1 at UIUC

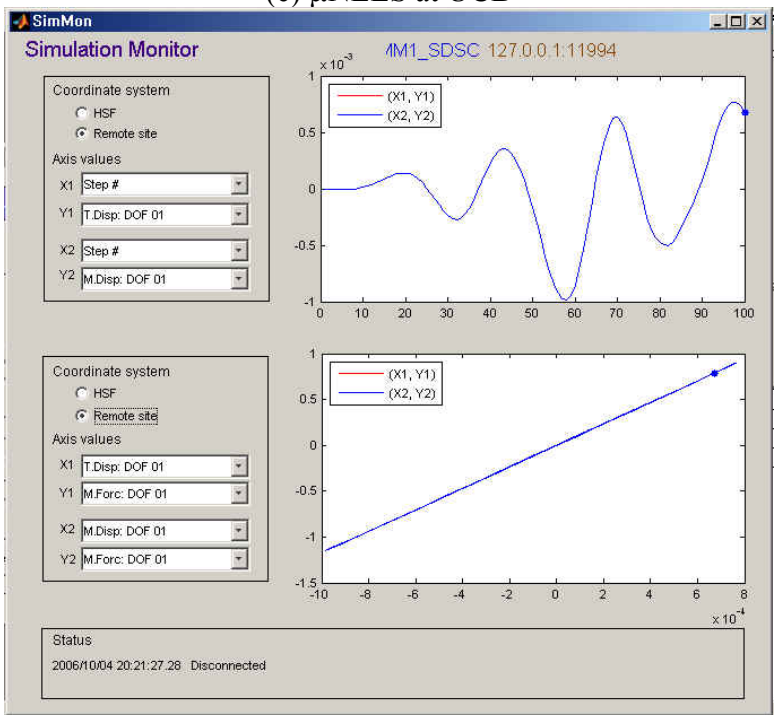


(b) ZEUS-NL at UIUC

Figure B-1 Responses of each site



(c) μNEES at UCB



(d) MM1 at SDSC

Figure B-2 Responses of each site - continued

Prepare the communication among UIUC, UCB, and SDSC

UIUC Site

1. Log on to the MiniMOST 1 computer and run a NEES-SAM API for MiniMOST 1 analytical model by double clicking **NEESSAM_LabView1.exe** which is located in C:\SIMCOR\03_Examples\ThreeSite\01_UIUC
   a. You will see the similar figure as shown in Figure B-2 (details in figure are dependent on the model).
   b. Check the status of NEES-SAM, module name, and port number

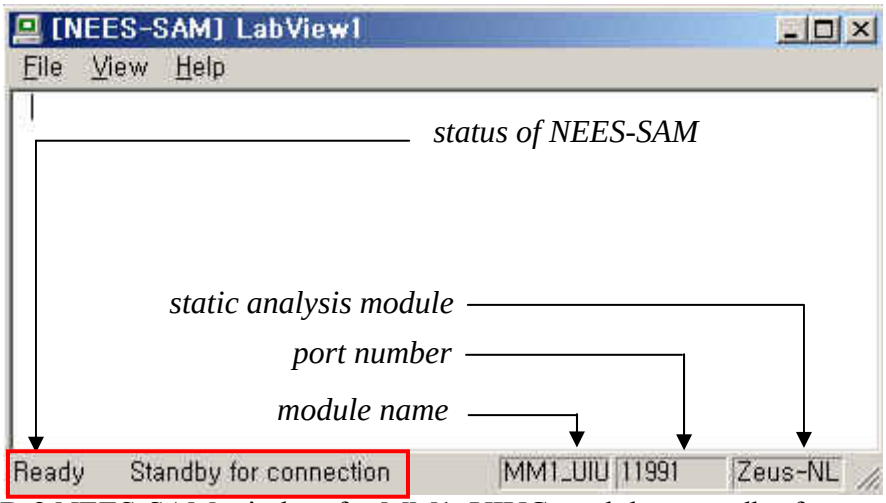


Figure B-2 NEES-SAM window for MM1_UIUC module – standby for connection

2. Log on to the Simulation Coordinator computer and run a NEES-SAM API for ZEUS-NL model by double clicking **NEESSAM_LabView2.exe** which is located in C:\SIMCOR\03_Examples\ThreeSite\02_Module2
   a. You will see the similar figure as shown in Figure B-2 (details in figure are dependent on the model).
   b. Check the status of NEES-SAM, module name, and port number

UCB Site

3. Log on to the μNEES control computer and run a NEES-SAM API for μNEES analytical model by double clicking **NEESSAM_LabView2.exe** which is located in C:\SIMCOR\03_Examples\ThreeSite\03_UCB
   a. You will see the similar figure as shown in Figure B-2 (details in figure are dependent on the model).
   b. Check the status of NEES-SAM, module name, and port number

SDSC Site

4. Log on to the MiniMOST 1 computer and run a NEES-SAM API for MiniMOST 1 analytical model by double clicking **NEESSAM_LabView1.exe** which is located in C:\SIMCOR\03_Examples\ThreeSite\04_SDSC
   a. You will see the similar figure as shown in Figure B-2 (details in figure are dependent on the model).
   b. Check the status of NEES-SAM, module name, and port number

Prepare the UI-SIMCOR for hybrid test

UIUC Site

5. Run a MATLAB in the Simulation Coordinator computer for UI-SIMCOR and change the directory to C:\SIMCOR\03_Examples\ThreeSite\00_Coordinator
6. Type **UI_SimCor** and enter in MATLAB command window to run UI-SIMCOR

New simulation
Please backup previous simulation results if necessary. All previous files will be deleted.
Okay
Cancel

Figure B-3 Warning message

   a. Click **Okay** button, then you will see the initialize message in a MATLAB command window. All previous files will be deleted, so if necessary backup previous results.
   b. Five popup windows will be displayed. One window for control and other windows for monitoring of each module will popup.
   c. Check the module name, IP address, and port number in the monitoring windows.

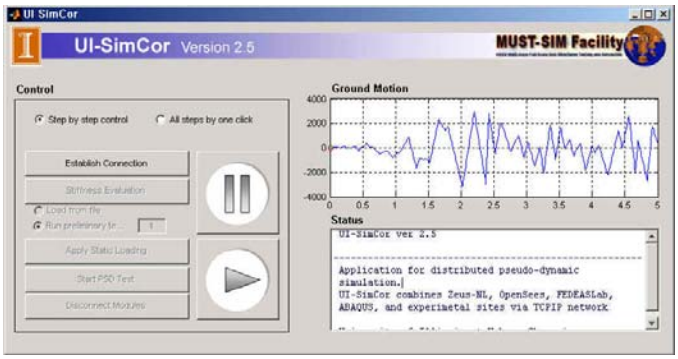
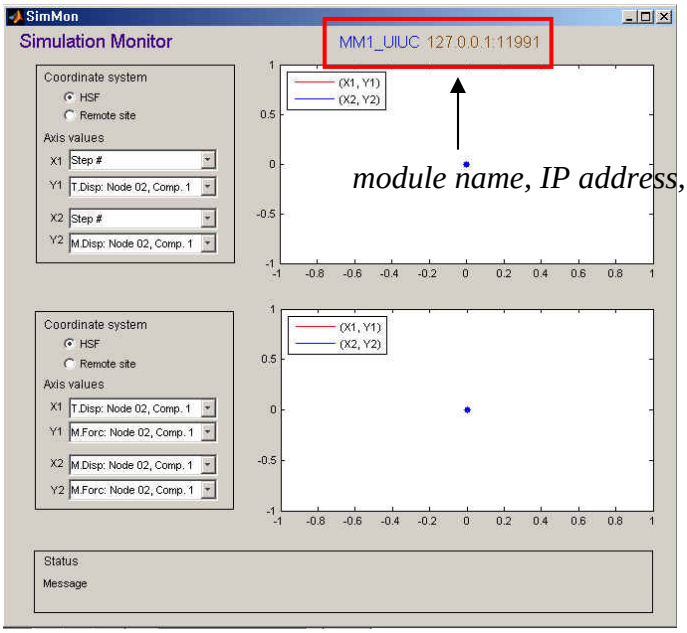


Figure B-4 Control window



module name, IP address, and port number

Figure B-5 Monitoring window

Now ready to run the three-site hybrid test - Simulation

Conduct the hybrid test

UIUC Site

7. Click **Establish Connection** button in UI-SIMCOR control window. You will see some messages indicating that the connection is established in a MALTAB command window and NEES-SAM API windows of each site.

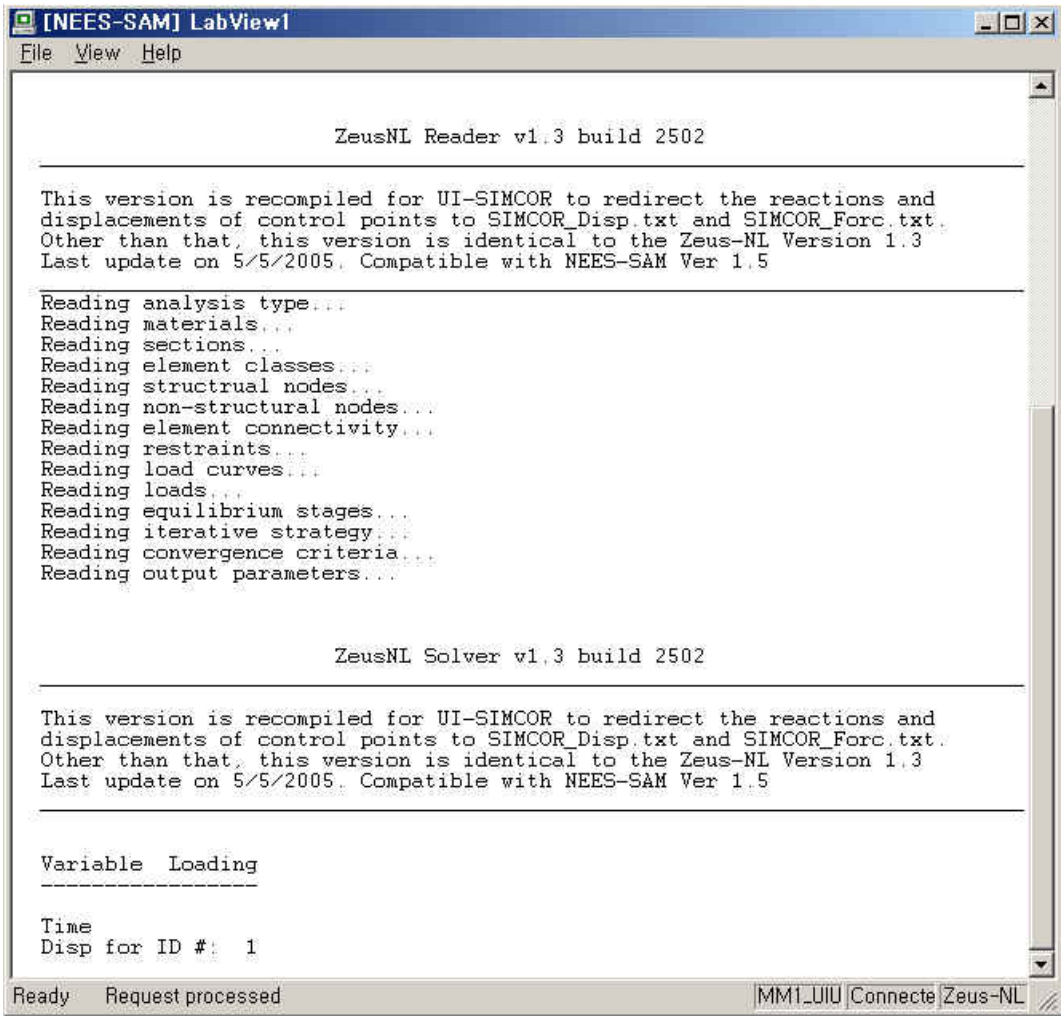

[NEES-SAM] LabView1
File View Help
ZeusNL Reader v1.3 build 2502
This version is recompiled for UI-SIMCOR to redirect the reactions and
displacements of control points to SIMCOR_Disp.txt and SIMCOR_Forc.txt.
Other than that, this version is identical to the Zeus-NL Version 1.3
Last update on 5/5/2005. Compatible with NEES-SAM Ver 1.5
Reading analysis type...
Reading materials...
Reading sections...
Reading element classes...
Reading structrual nodes...
Reading non-structural nodes...
Reading element connectivity...
Reading restraints...
Reading load curves...
Reading loads...
Reading equilibrium stages...
Reading iterative strategy...
Reading convergence criteria...
Reading output parameters...
ZeusNL Solver v1.3 build 2502
This version is recompiled for UI-SIMCOR to redirect the reactions and
displacements of control points to SIMCOR_Disp.txt and SIMCOR_Forc.txt.
Other than that, this version is identical to the Zeus-NL Version 1.3
Last update on 5/5/2005. Compatible with NEES-SAM Ver 1.5
Variable Loading
Time
Disp for ID #: 1
Ready
Request processed
MM1_UIU Connecte Zeus-NL

Figure B-6 NEES-SAM window for MM1_UIUC module – after establish connection

8. Click **Stiffness Evaluation** button in UI-SIMCOR control window. UI-SIMCOR will read the predefined stiffness matrix from files (MDL01_K.txt, MDL_02.txt, MDL_03.txt, and MDL_04.txt) located in C:\SIMCOR\03_Examples\ThreeSite\00_Coordinator.
9. Click **Apply Static Loading** button in UI-SIMCOR control window. In this stage, the gravity force is applied, however, there is no plan to apply gravity as this exemplary test is to demonstrate the efficacy of hybrid simulation framework.
10. Click **Start PSD Test** button in UI-SIMCOR control window to run test by simulation. The target displacement and feedback displacement and force will be displayed in the monitoring windows in UIUC site. Furthermore, current status of test will be displayed in NEES-SAM API of each site as shown in Figure B-7.

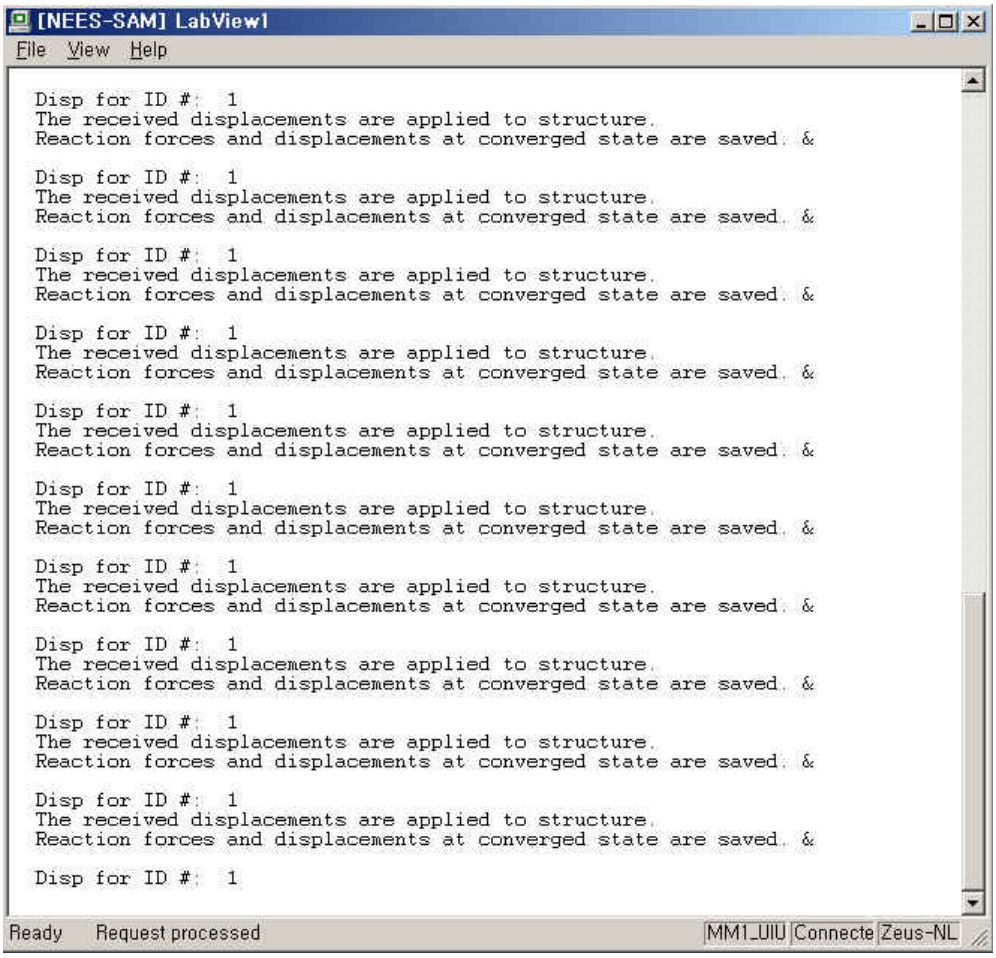


Figure B-7 NEES-SAM window for MM1_UIUC module – during PSD test

11. Click **Disconnect Modules** button in UI-SIMCOR control window after finishing hybrid simulation to disconnect UI-SIMCOR from each site. You will see some messages indicating the communication is disconnected in a MALTAB command window and NEES-SAM API of each site.

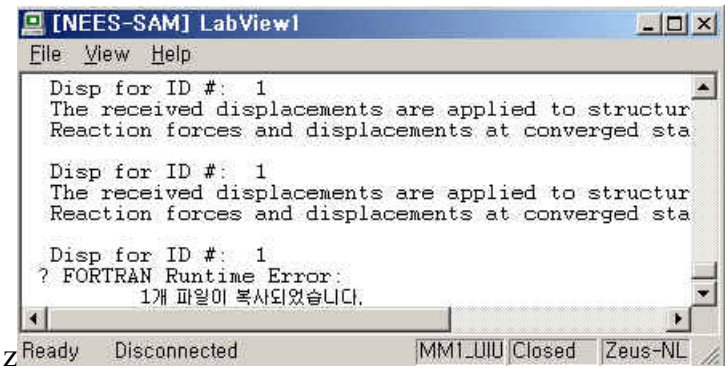


Figure B-8 NEES-SAM window for MM1_UIUC module – after disconnecting

12. Backup the results files and send to UIUC
    a. For UIUC site
        - MDL01_recv.txt, MDL02_recv.txt, MDL_03_recv.txt, MDL04_recv.txt,

Netwklog.txt, and NodeDisp.txt located in
C:\SIMCOR\03_Examples\ThreeSite\00_Coordinator
- Cur_Disp.txt, Cur_Forc.txt, and Netlog.txt located in
C:\SIMCOR\03_Examples\ThreeSite\01_UIUC
- Cur_Disp.txt, Cur_Forc.txt, and Netlog.txt located in
C:\SIMCOR\03_Examples\ThreeSite\02_Module2

b. For UCB site
- Cur_Disp.txt, Cur_Forc.txt, and Netlog.txt located in
C:\SIMCOR\03_Examples\ThreeSite\03_UCB

c. For SDSC site
- Cur_Disp.txt, Cur_Forc.txt, and Netlog.txt located in
C:\SIMCOR\03_Examples\ThreeSite\04_SDSC

B-2 Step 2: Hybrid test by experiment (500 steps)

This is experiment, so it will send target displacement to each site.

The purpose of this step is to conduct the actual three-site hybrid experiment among UIUC, UCB, and SDSC. **UI-SIMCOR**, **MiniMOST 1**, **ZEUS-NL model** (UIUC), **μNEES** (UCB), and **MiniMOST 1** (SDSC) will be tested.

For this test, following IP address and port number of each site will be used.

For MM1 at UIUC : 130.126.240.138:44000
For μNEES at UCB : 169.229.203.152:8090
For MM1 at SDSC : 137.110.118.95:44000

The same displacement limit with step 1 is also used in this step.

The experimental procedure introduced in this section is very simple, so if necessary more detailed information running the MiniMOST LabVIEW code can be found in http://users.sdsc.edu/~hubbard/neesgrid/mmost/ and *User's Manual of MUST-SIM Facility* (UIUC, 2005).

Prepare the communication among UIUC, UCB, and SDSC

UIUC Site

For MiniMOST 1 @ UIUC

1. Turn on the MiniMOST 1 system.
2. Log on to the MiniMOST 1 computer and open the lv-programs folder located on the Desktop.

3. Double click on the daemon-programs icon in this folder. It should bring up a list of LabVIEW programs. Choose **Control daemon.vi** from this menu, and click **OK**. You will see the Figure B-9.

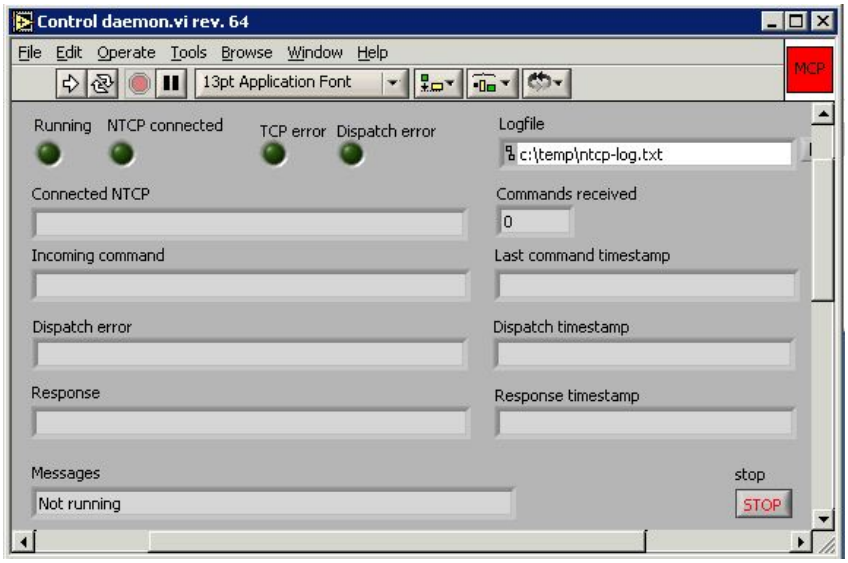


Figure B-9 Control daemon in daemon-programs

   a. The control daemon program receives NTCP commands. In order to start its ability to receive NTCP commands, click on the white arrow located on the toolbar of this LabVIEW program.

4. Now double click on the mini-most icon located in the lv-programs folder that was opened on the Desktop. Choose **Control program.vi** from the menu of LabVIEW programs, and click **OK**. You will see the Figure B-10.

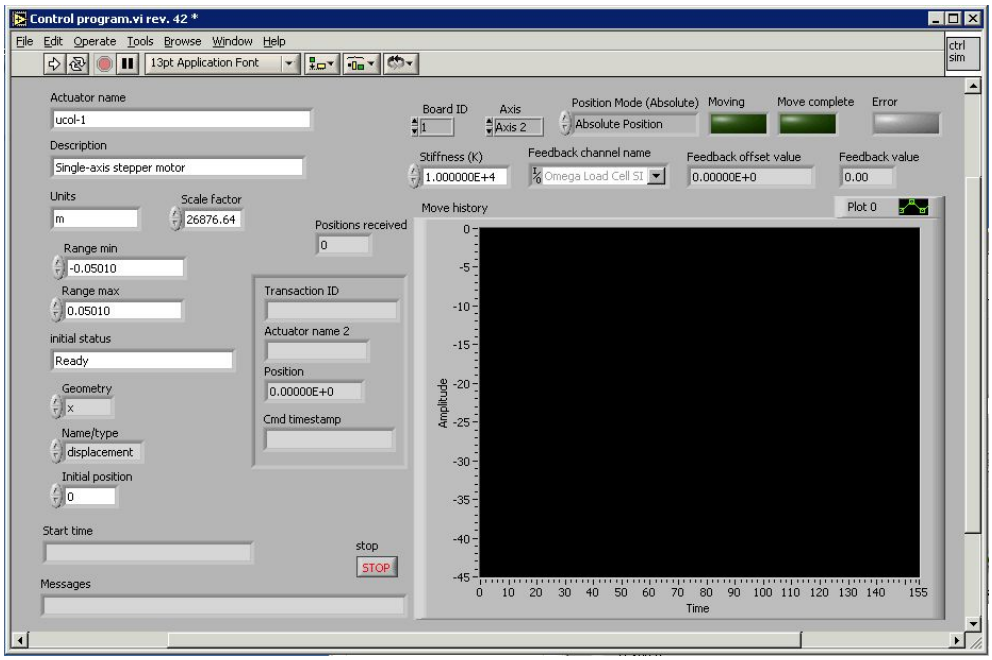


Figure B-10 Control program in mini-most

a. The control program commands MiniMOST 1 to execute the target displacements sent from UI-SIMCOR by controlling the motor. None of the variables need to be changed in this program. To start receiving target displacements, click on the white arrow located in the toolbar.

For ZEUS-NL model @ UIUC

5. Log on to the Simulation Coordinator computer and run a NEES-SAM API for ZEUS-NL model by double clicking **NEESSAM_LabView2.exe** which is located in C:\SIMCOR\03_Examples\ThreeSite\02_Module2
   a. You will see the similar figure as shown in Figure B-2 (details in figure are depends on the model).
   b. Check the status of NEES-SAM, module name, and port number

UCB Site

For μNEES @ UCB

6. Install the coupon at specimen.
7. Restart the xPC Real-time target
8. Log on to the μNEES control computer and run a MATLAB for communication with xPC Real-time target and change the directory to C:\SIMCOR\04_API\01_UCB
9. Type **API_Main**, then you will see the message box confirming the displacement limit as shown in Figure B-11.

Check Displacement Limit
Current displacement limit for UCB speicmen: 6.00e+000
If you want modify the displacement limit, please open API_Main.m
Okay
Reset

Figure B-11 Warning message

   a. The displacement limit in the **API_Main** is 6, however the displacement limit in the **SimConfig** of UI-SIMCOR is 2. So if the target displacement which will be sent to xPC Real-time target is greater than 2, the test will be paused with warning message in UI-SIMCOR control window
   b. If the displacement limit is confirmed, click **Okay** button, then you will see the "Waiting for connection from client through port 8090 …" in a MATLAB command window.
   c. If you want modify the displacement limit, click **Reset** button, then the **API_Main** file is opened automatically. Modify the Disp_Limit variable at line 17.

SDSC Site

For MiniMOST 1 @ SDSC

10. Turn on the MiniMOST 1 system.
11. Log on to the MiniMOST 1 computer and open the lv-programs folder located on the Desktop.
12. Double click on the daemon-programs icon in this folder. It should bring up a list of LabVIEW programs. Choose **Control daemon.vi** from this menu, and click **OK**. You will see the Figure B-9.
    a. The control daemon program receives NTCP commands. In order to start its ability to receive NTCP commands, click on the white arrow located on the toolbar of this LabVIEW program.
13. Now double click on the mini-most icon located in the lv-programs folder that was opened on the Desktop. Choose **Control program.vi** from the menu of LabVIEW programs, and click **OK**. You will see the Figure B-10.
    a. The control program commands MiniMOST 1 to execute the target displacements sent from UI-SIMCOR by controlling the motor. None of the variables need to be changed in this program. To start receiving target displacements, click on the white arrow located in the toolbar.

Prepare the UI-SIMCOR for hybrid simulation

UIUC Site

14. Run a MATLAB in the Simulation Coordinator computer for UI-SIMCOR and change the directory to C:\SIMCOR\03_Examples\ThreeSite\00_Coordinator
15. Type **UI_SimCor** and enter in MATLAB command window to run UI-SIMCOR
    a. You will see the warning message shown in Figure B-3.
    b. Click **Okay** button, then you will see the initialize message in a MATLAB command window. All previous files will be deleted, so if you want please backup previous results.
    c. Five popup windows will be displayed. One window for control and other windows for monitoring of each module will popup.
    d. Check the module name, IP address, and port number in the monitoring windows.

Now ready to run the three-site hybrid test - Experiment

Conduct the hybrid test

UIUC Site

16. Click **Establish Connection** button in UI-SIMCOR control window. You will see some messages indicating that the connection is established in a MALTAB command window.
    a. Additional simulation monitor of GUI for UCB site will be displayed in the μNEES control computer as shown in Figure B-12. This GUI helps UCB site seeing current statues of experiment. SDSC site does not have this GUI for current test.
    b. The status of NEES-SAM window for ZEUS-NL model is changed to Initializing from Standby for connection.

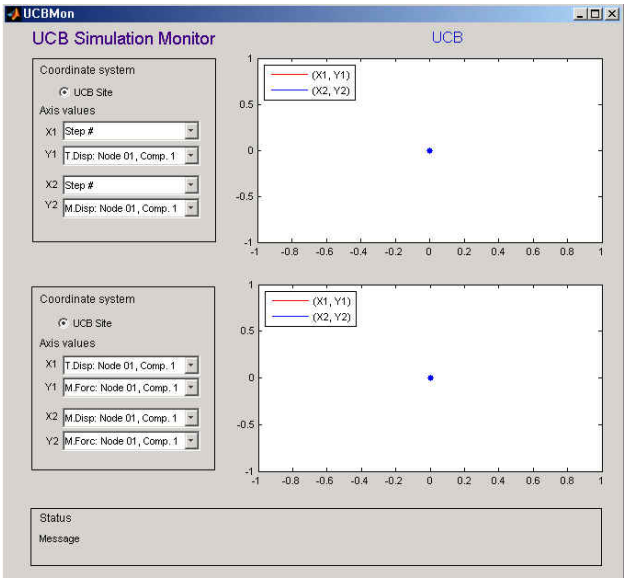


Figure B-12 Monitoring window for UCB site

17. Click **Stiffness Evaluation** button in UI-SIMCOR control window. UI-SIMCOR will read the predefined stiffness matrix from files (MDL01_K.txt, MDL_02.txt, MDL_03.txt, and MDL_04.txt) located in C:\SIMCOR\03_Examples\ThreeSite\00_Coordinator
18. Click **Apply Static Loading** button in UI-SIMCOR control window. In this stage, the gravity force is applied, however, there is no plan to apply gravity as this exemplary test is to demonstrate the efficacy of hybrid simulation framework.
19. Click **Start PSD Test** button in UI-SIMCOR control window to conduct the **experiment**. The target displacement and feedback displacement and force will be displayed in the monitoring windows in UIUC site. For UCB site, the target displacement and measured displacement and force in remote site (not HSF) will be displayed in GUI.

20. Click **Disconnect Modules** button in UI-SIMCOR control window after finishing hybrid simulation to disconnect UI-SIMCOR from each site. You will see some messages indicating the communication is disconnected in a MALTAB command window and API of each site.
21. Backup the results files and send to UIUC
    a. For UIUC site
        - MDL01_recv.txt, MDL02_recv.txt, MDL_03_recv.txt, MDL04_recv.txt, Netwklog.txt, and NodeDisp.txt located in C:\SIMCOR\03_Examples\ThreeSite\00_Coordinator
        - Cur_Disp.txt, Cur_Forc.txt, and Netlog.txt located in C:\SIMCOR\03_Examples\ThreeSite\02_Module2
    b. For UCB site
        - NetwkLog.txt, UCB_Results.txt located in C:\SIMCOR\04_API\01_UCB